THE DEVELOPMENT OF A METHOD TO LOAD JP4 ABOARD TANKERS WHICH

PROTECTS ITS ANTI-ICING PROPERTIES, ELIMINATES TANK DRYING, AND

RESULTS IN SIGNIFICANT SAVINGS IN TIME AND MONEY

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by /5

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## ABSTRACT

The jet fuel currently used by the United States Air
Force requires an anti-icing additive because of the long
range, high altitude aircraft now in use. When transporting
this jet fuel by tanker, all water must be removed from the
vessel's tanks since the additive is highly soluble in water.
In his three years experience as a petroleum inspector, the
author has observed that tankers lifting JP4 are delayed
approximately 12 hours per cargo at a cost of approximately
$2,000 per cargo because of this tank drying requirement.
Upon assignment to the University of Kansas in the Navy
sponsored Petroleum Management Post Graduate Program, the
author undertook,as his thesis project, the development of a
less costly method of loading JP4, basing his study primarily
upon laboratory tests but realizing that actual field tests
would be required for conclusive results.

Laboratory tests conducted indicate that the icing
inhibitor concentration in the fuel may be maintained within
the military specification limits of 0.10-0.15 per cent as
long as a sufficient quantity of inhibitor is injected to
satisfy the equilibrium concentration requirement of the water
remaining aboard the vessel after normal deballasting. In
most cases, no more icing inhibitor is required than is
called for by the maximum military specification limit. Tests
conducted at the University of Kansas and the author's own

experience in loading tankers indicate that extensive savings in time and money may be realized by using the proposed method. Using the new method could result in a savings of approximately 12 hours turn-a-round time per cargo lifted, a savings which is of immediate significance to the military. By using the new method, a savings of approximately $2,000 per cargo in drying time could also be realized, a savings of immediate significance to tanker operators. On a yearly basis, the author estimates that more than 4,000 hours in tanker turn-a-round could be saved as well as $700,000 in drying costs. The author recommends, therefore, that field tests be conducted using actual vessels and that if these tests are successful the new method be adopted as soon as possible.

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F. W. M.

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS

# LIST OF TABLES

# CHAPTER I

## INTRODUCTION

### Icing Problems in the Jet Age

During the past 10 years the turbo-prop and turbo-jet aircraft have become dominant in military air defense. The development of the jet aircraft required new construction and new design techniques. Many features of conventional piston engine planes were adaptable to new jet aircraft and were incorporated in their construction. One such feature was the application of heat at critical points in the fuel system where moisture caused icing problems. The fuel heater at the filter in the jet aircraft performed the same function as the carburetor heater in the piston engine plane.

The jet fuel, grade JP4, used by the United States Air Force is a lighter and more volatile product than that used by most commercial airlines. Specification requirements limit the gravity to between 45-57° A.P.I. The fuel itself must have a freezing point of -72°F or below. JP4 normally contains 70-100 parts per million of water in solution.[1] This small quantity of water causes the basic problem since at high altitude or low ground temperatures, the water present in the fuel condenses and deposits of ice are formed on fuel system parts.

By 1958 it became apparent that the icing problem was not solved. The newer, high altitude, long range jets exper-

1

ienced a variety of icing problems including malfunction tendencies of fuel controls, ice plugging of fuel filters, and freeze-up of fuel boost and transfer pumps. The most serious problem of all was engine flame out. Since fuel heaters in operational aircraft were not providing adequate icing protection, and aircraft designers could not, in many cases, incorporate larger fuel heaters into future aircraft, a new approach to the icing problem was taken.

In June of 1958, the United States Air Force invited chemical and petroleum companies to participate in a search for a fuel additive which would eliminate the icing problem. By 1962 an icing inhibitor developed by the Phillips Petroleum Company, PFA 55MB, had been thoroughly tested and was accepted by the Air Force. In September of 1962 the JP4 specification, MIL-T-5624, was formally modified requiring the addition of icing inhibitor in concentrations of 0.10-0.15 per cent by volume. The present JP4 specification, MIL-T-5624G, is included as Appendix A. The icing inhibitor in use today is a modified composition of the original inhibitor developed and consists of 99.6 per cent ethylene glycol monomethyl ether and 0.4 per cent glycerol by weight. MIL-27686D is the military specification now in use and is included as Appendix B.

## The JP4 Transportation Problem

One of the greatest problems which originated with the requirement for the additive arose in the transportation

field. The additive is highly soluble in water and migrates from the fuel into any water with which it comes into contact. When JP4 is shipped by vessel, water contact is difficult to prevent. Unfortunately, the additive has no preference and acts on sea water the same as fresh water. Due to the great demand for JP4, the usual shipment is by full tanker lot. Tankers scheduled for JP4 lifts proceed from their previous discharge port to loading port without cargo, but must necessarily carry sea water ballast for stability. In most cases ballast must be distributed equally throughout the ship to prevent excessive stress on the longitudinal members. Because of absorption of the additive by water, all free sea water is removed from a vessel's tanks prior to loading JP4. The water removal operation consists of sending men down into all cargo tanks with buckets and mops or eductors to remove any free water which remains after the vessel has pumped out the sea water ballast. This operation is very costly to the carrier. Not only is the shipping company paying normal wages to the entire crew during the drying operation, but also a premium pay rate to the men who are working in the tanks.

The drying operation creates problems for the refiner. The time required to dry a vessel's tanks can not be predicted with a great degree of accuracy. While a vessel is drying tanks at the pier, the refiner must schedule pier space for waiting vessels and expected arrivals. One JP4 ship in port

can easily cause costly scheduling delays and inefficient
use of loading lines.

The cargo purchaser is also faced with problems when
tank drying is required. He is indirectly paying for the
drying time in higher freight rates. In some cases he must
either wait days past his expected delivery date to receive
the cargo or divert a cargo in transit to where it is most
needed. Cargo diversions compound his scheduling problems.

## Purpose of Thesis

While working as a U.S. Navy Petroleum Inspector in
the Caribbean area, the author became aware of the difficul-
ties encountered in loading JP4 and considered that possibly
the difficulties could be reduced if a better method could be
developed for solving the problem presented by the small
amounts of water remaining in a vessel's tanks after deballast-
ing. A better understanding of the mechanism of icing in-
hibition could also be of great value to military personnel
in operating fuel billets. The purposes of this thesis
therefore are to:

1. Provide a source of information to Military Petroleum
   Offices at the working level which will promote a bet-
   ter understanding of the process of distribution of
   the anti-icing additive between fuel and water.

2. Investigate the economic feasibility of eliminating
   the drying of a vessel's tanks when lifting JP4 by
   increasing the anti-icing content of the fuel by the

amount which will be absorbed in any water remaining after normal deballasting.

3. Provide a time-saving method to load JP4 in an emergency, regardless of cost.

# CHAPTER II
## TANKER OPERATIONS

### Introduction

In 1966, approximately 153,837,000 barrels of jet
fuel, grade JP4, were purchased by the United States Air
Force. Of this amount, approximately 48,300,000 barrels were
transported by tanker to their destination.[2] Tankers which
carry military products can be divided into two groups:
those in black service and those in clean service. The
black service tankers carry products such as Bunker "C" and
Navy Special Fuel Oil while the clean service tankers carry
diesel fuels, motor gasoline, kerosine, jet fuel, and avia-
tion gasoline. Jet fuel, being in the clean product category,
is carried exclusively aboard clean service tankers, and it
is this type of tanker which will be discussed. It should
be noted that there is no apparent physical difference between
the tankers in clean and in black service. The clean service
tankers discussed are not to be confused with Fleet Oilers.
The ships under discussion are Navy owned, civilian manned
tankers and civilian owned and operated ships chartered by
the Military Sea Transportation Service.

There are so many classes of tankers in use today that
it would be impossible to discuss the differences of each.
The same basic procedures in preparation for loading are re-
quired by every ship. The smallest tanker still in wide use

6

by the military has been selected as the basis for study
since its size contributes to providing the most severe test
case. That is to say, if the proposal presented has merit
using a small tanker, it is expected that a larger tanker
will produce even better results. The type tanker selected
was the 16,000 dead weight ton ship designated T2. The Mili-
tary Sea Transportation Service has approximately 16 T2's in
clean service operation. A T2 normally carries from 135,000
to 138,000 barrels of JP4, depending on the gravity of the
product. The ship has 26 cargo tanks, 9 wing tanks on each
side with 8 center tanks between. Figure 1 is a top view of
a T2 showing the cargo tank arrangement.
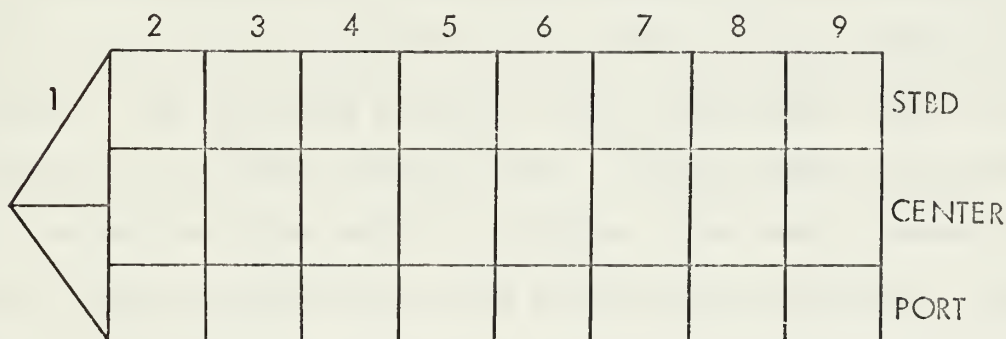


Figure 1 - T2 Cargo Tank Arrangement

## Tank Cleaning

After discharging cargo, a tanker must take on sea
water ballast prior to leaving the pier. This is necessary
for stability and steering control of the ship. The ship's
sea suctions, located in the pumproom, are opened and sea

water passes from the pump room through the below deck main lines and into the cargo tanks.

If a product other than the one just carried is to be lifted next, a thorough cleaning of the vessel's tanks is mandatory. In the event the same product is to be carried again, normal procedure would require no tank cleaning. JP4 is the exception to this procedure. In order properly to inspect a vessel which is to load JP4, it is necessary for an inspector actually to enter the tanks in order to determine that there is no free water. The tanks must be gas free, a condition which can only be accomplished by a thorough cleaning.

Tank cleaning is a costly operation. It involves the removal of the previous product from cargo tanks, pipelines, and pumps. The cleaning process takes place while the ship is enroute to its next loading port. Cargo tanks are washed with a mechanical type washing machine. The most common type machines used are the Pyrate and Butterworth machines. High pressure streams of hot or cold water are discharged from the washing machine nozzles to clean the tanks. Figure 2 shows a typical tank washing machine.
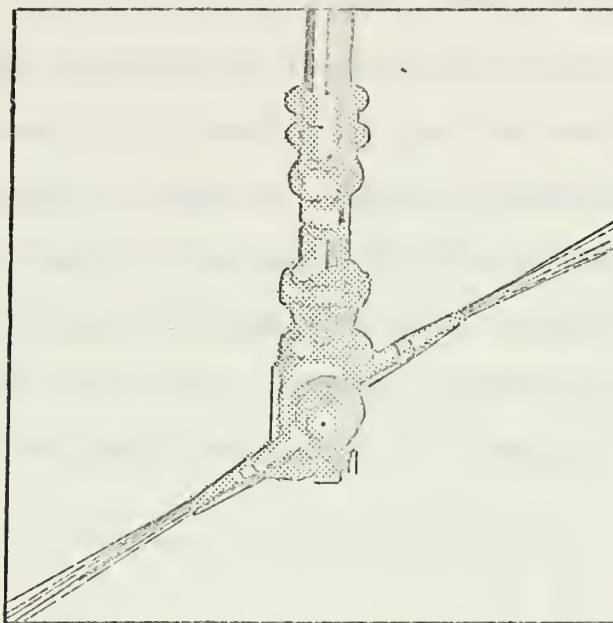
Figure 2 - Tank Washing Machine[3]

Sea water is passed through the fire and tank washing pumps
where pressure is boosted.  If hot water is desired, heat is
then applied enroute to the tank washing machine.  The machine
is suspended from the top of the tank and slowly lowered to
various levels at specific time intervals depending on the
degree of cleanliness desired.  As the water passes through
the nozzles, they are rotated vertically and at the same time
a circular horizontal motion occurs which insures that the
stream contacts all visible surface areas inside the tank.

The application of heat and additional pump power
during tank cleaning increases fuel consumption by the vessel
and in many cases reduces the vessel's speed.

A tanker lifting a clean product other than jet fuel
proceeds to the dock and pumps out the sea water ballast

from all tanks. Each tank has a main suction valve through
which any product entering or leaving the tank must pass.
Each tank also contains a stripping suction smaller than the
main suction, which is used to pump out product which remains
after suction is lost at the main suction valve. The strip-
ping suction is located behind the main suction against the
after bulkhead of each tank. Figure 3 shows the locations
of the main and stripping suctions in a cargo tank.
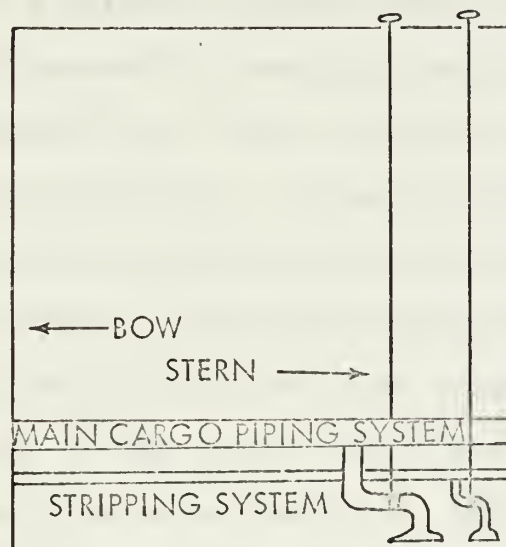


Figure 3 - Main and Stripping Suctions
in a Cargo Tank

As soon as suction is lost by the main cargo pump
system, the stripping system is activated. This system is
independent of the main cargo system and removes as much water
as is possible with the use of a pump. As soon as stripping
is completed and the vessel has passed inspection, cargo
loading is commenced.

Tank Drying

In the case of a vessel loading JP4, as soon as strip-
ping is completed in the forward tanks, they are sealed off
from the after tanks by means of pipeline block valves.  All
tank valves are opened allowing any water remaining in the
pipelines forward of the block valves to drain back into the
tanks.  Men with buckets and mops proceed down into each tank
which is from 40-45 feet deep.  The remaining water which
consists of about 25 gallons per wing tank and 40-50 gallons
per center tank is removed by scooping the water into buckets
and lifting the buckets on a line, by hand, to the top of the
tank where they are poured out.  After the water quantity is
very low, mops are used in place of the scoops and wrung out
by hand into the buckets.  Some ships use portable eductors
for the removal of water, and some have compressed air motors
to raise the buckets to the top of the tank.  A tank is con-
sidered dry when no free water remains.  The drying procedure
is repeated in each of the 26 cargo tanks aboard a T2 and
requires from 4 to over 100 hours.  Drying time, as recorded
on the cargo papers, starts when the vessel has completed
pumping ballast and ends when the last tank is dry.

T2 drying time taken from 12 inspection reports issued
in 1966-67 averaged 8.6 hours per ship.  Data reported by
several classes of ships on 10 loading reports during 1967
indicated an average drying time of 21.4 hours per ship.  The
average hourly cost to operate a T2 tanker is $164.00.[4]  An

additional cost is incurred while the vessel is at the dock
drying tanks since premium rates are paid to men in the tanks.

The hazards of working in a ship's tank can not be
over emphasized. The ladders in the tanks are usually damp
and slippery. In some ships, the ladders are vertical which
makes descent even more dangerous. Even after a thorough
machine cleaning, product vapors are sometimes given off which
can cause dizziness or asphyxiation. If there is any doubt
as to whether a tank is gas free, a gas detector is used to
determine if any vapors are present in the tank. Blowers are
sometimes required when tank cleaners are working in order
to keep the vapor concentrations to a minimum. In addition
to the breathing problem caused by vapors, an explosive mix-
ture in the tank is very dangerous, especially when lamps are
lowered to assist in the tank cleaning operation.

Cargo Loading

After tank drying has been completed and the ship
passes inspection, cargo loading is commenced. Cargo is
loaded from the manifold on deck either through drop lines
which run vertically into the lower pipelines in tanks 5
center and 7 center or back to the pump room, down vertical
piping and up the fore and aft lines into the ship's cargo
tanks. Figure 4 shows the main piping system of a T2 tanker.
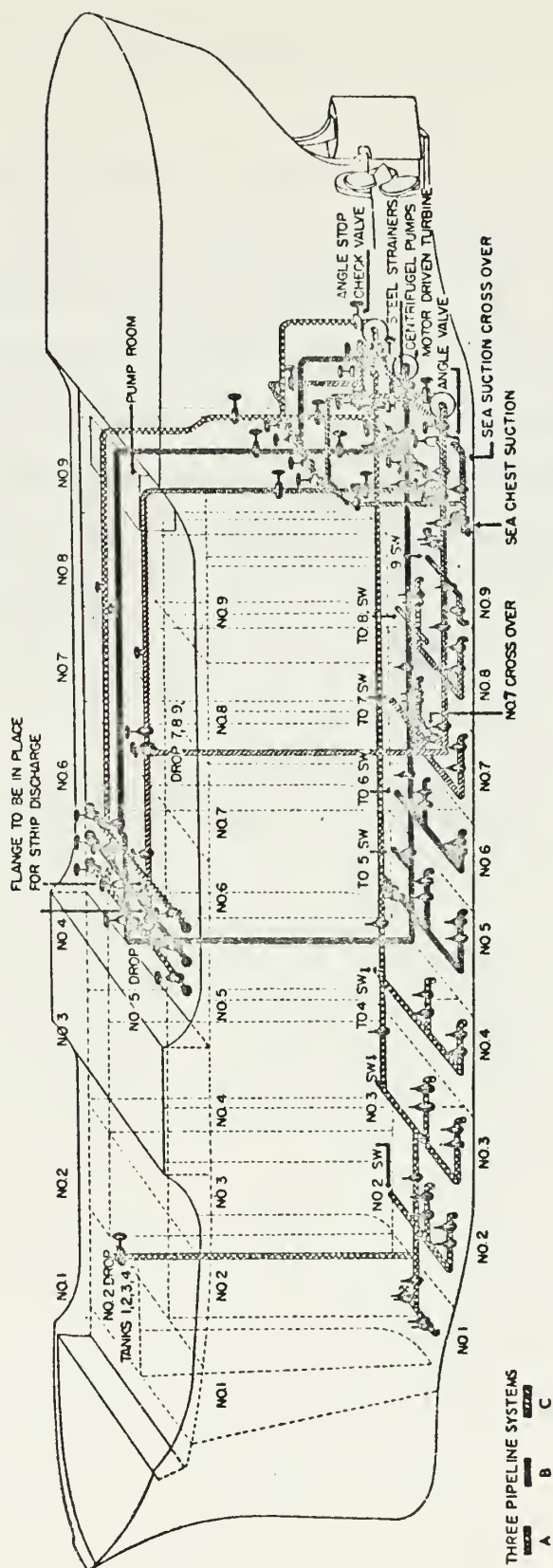
Figure 4. – Pipeline and Valve System of a T-2 Tanker[5]

## Summary

Vessels lifting JP4 cargoes are faced with the following problems.

1.  Costly drying time at the pier prior to loading.

2.  Danger of injury to personnel due to falls or asphyxiation in ships' tanks.

3.  Vessels lifting successive JP4 cargoes must clean tanks while enroute to the next loading port. This cleaning operation increases fuel consumption and reduces speed. It would not be required if tank drying were eliminated.

# CHAPTER III

## THE ADDITIVE, ITS PROPERTIES AND
## INJECTION PROCEDURES

### Introduction

The military specification requirement for JP4 icing
inhibitor may be found in Appendix B. The inhibitor consists
of 99.6 per cent ethylene glycol monomethyl ether and 0.4 per
cent glycerol by weight. The major component provides the
icing protection desired while the minor component is added
to protect the interior coatings of aircraft fuel tanks.
The additive is soluble in jet fuel from 30 to 100 times its
specified concentration of 0.10 to 0.15 per cent by volume.[6]
It is completely soluble in water either entrained in or in
contact with the fuel. The additive is uniquely suited to
its purpose since it will migrate to water in contact with
fuel in a predictable but not excessive manner. Even though
the additive will migrate to water, its equilibrium concen-
trations in both free water and the fuel are most desirable
in accomplishing its purpose.

### The Partition Coefficient

A substance which is soluble in both phases of a two
phase liquid system will distribute itself between the two
phases. When equilibrium is reached, the ratio of the concen-
trations of the substance in the two phases is called the
partition coefficient. At constant temperature and pressure

15

the partition coefficent remains constant.[7] The amount of
additive which will be absorbed by a particular quantity of
water depends on the temperature, the fuel/water ratio and
the concentration of the additive in the fuel. All of these
effects may be taken into account by means of a partition
coefficent. The partition coefficent (K), is defined below.

If: $(A_f)_o$ = volume of additive in the fuel initially

F = volume of fuel

$W_o$ = initial volume of water in contact with the
fuel

$A_w$ = volume of additive in water at equilibrium

$A_f$ = volume of additive in fuel after equilibrium

W = volume of water including the additive after
equilibrium

Let $y = \dfrac{A_f(volume)}{F\ (volume)}$ and $x = \dfrac{A_w(volume)}{W\ (volume)}$

Then $K = \dfrac{x}{y}$

The volume of additive which migrates to the water can be de-
termined as follows:

$$\frac{KA_f}{F} = \frac{A_w}{W}$$

$$W = W_o + A_w$$

$$\frac{KA_f}{F} = \frac{A_w}{W_o + A_w}$$

$$\frac{K\left[(A_f)_o - A_w\right]}{F} = \frac{A_w}{W_o + A_w}$$

$$\left[-\frac{K}{F}(A_f)_o - \frac{K}{F}A_w\right]\left[W_o + A_w\right] = A_w$$

Multiplying

$$\frac{KW_o(A_f)_o}{F} - \frac{KW_o A_w}{F} - \frac{K(A_f)_o A_w}{F} - \frac{K A_w^2}{F} - A_w = 0$$

Changing signs and rearranging

$$\left[\frac{K}{F}\right]A_w^2 - \left[\frac{K W_o}{F} - \frac{K (A_f)_o}{F} + 1\right]A_w - \frac{KW_o (A_f)_o}{F} = 0$$

If the K value is known, the equation may now be solved by
the quadratic formula.

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad \text{or}$$

$$A_w =$$

$$\frac{-\left[\frac{K W_o}{F} - \frac{K(A_f)_o}{F} + 1\right] \pm \sqrt{\left[\frac{K W_o}{F} - \frac{K(A_f)_o}{F} + 1\right]^2 - 4\left[\frac{K}{F}\right]\left[\frac{KW_o(A_f)_o}{F}\right]}}{2\left[\frac{K}{F}\right]}$$

The percentage of additive in the water is determined as fol-
lows:

$$A_w(\%) = \frac{A_w (100)}{A_w + W_o}$$

The Research and Development Department of the Phillips Petrol-
eum Company has determined the partition coefficient (K) of
military icing inhibitor to be 220 at 80°F.[8]  It is this value

which will be used in the thesis computations since the laboratory tests were conducted at approximately 80°F. The three factors which affect the quantity of additive absorbed into a water phase are discussed below.

1. Temperature

As the temperature decreases, the partition coefficient increases. More of the additive migrates to the water phase, which is exactly what is required to prevent the water from freezing as the temperature drops. Under all conditions encountered thus far in aircraft fuel tanks, additive migration has not significantly depleted the additive content of the fuel itself.[9] The Phillips Petroleum Company has determined the partition coefficient at 0°F to be 480. It is assumed that a reasonable estimate of the partition coefficient at any temperature may be determined by using the relationship shown in Figure 5.[10]

2. Fuel/Water Ratio

The fuel/water ratio affects the migration of the additive to free water. As the fuel to water ratio increases, the amount of additive which migrates to the water increases.

3. Additive Concentration in Fuel

The quantity of icing inhibitor which migrates to the water phase is also dependent on the additive concentration in the fuel. As the additive concentration in the fuel is in-

FIGURE 5
PARTITION COEFFICIENT VERSUS TEMPERATURE
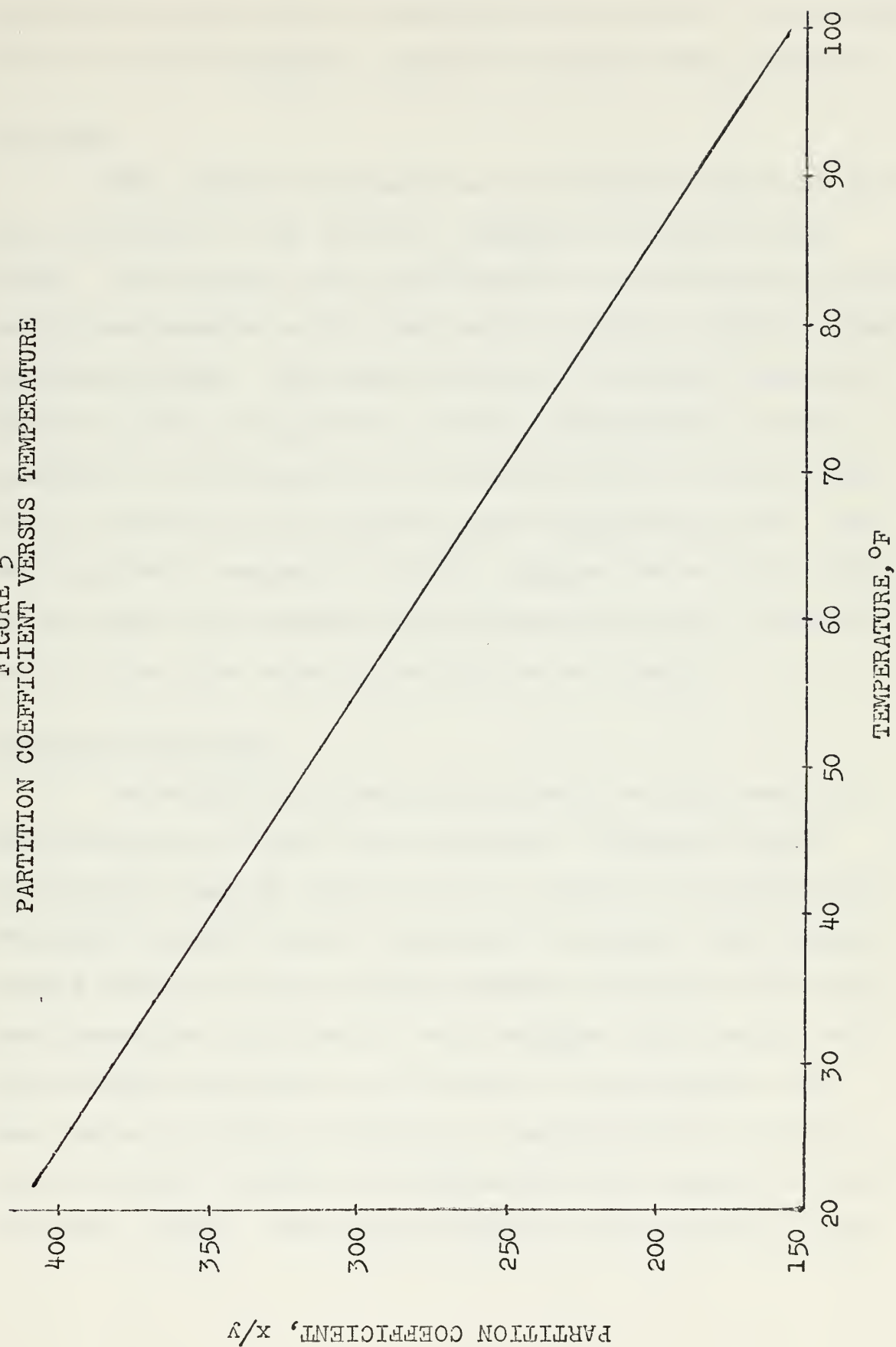
creased the percentage of additive which migrates to the water phase is also increased. Figure 6 indicates this property.

## Glycerol

The glycerol component in the additive serves to prevent softening of the interior coatings of aircraft fuel tanks. An aircraft wing tank interior is not subject to softening when exposed to dry fuel with or without ethylene glycol monomethyl ether. The tank interior is, however, subject to softening and peeling when in contact with water, and this condition is accelerated if the interior is in contact with water containing only ethylene glycol monomethyl ether. The minor glycerol component actually reduces the softening effect of the water and ethylene glycol monomethyl ether combination to less than that experienced with water alone.[11]

## Biocidal Protection

An additional beneficial property was discovered in the development of the icing inhibitor. Ethylene glycol monomethyl ether was found to be an excellent biocidal agent. Microbial growths in the wing tanks of aircraft have always caused concern to the aircraft industry since once the organisms penetrate the interior tank coatings, the aluminum surfaces below are subject to corrosion. The organisms must have water to exist and thrive at the fuel-water interface since the fuel provides the hydrocarbon food supply necessary for their growth. The icing inhibitor which migrates to the

FIGURE 6

ADDITIVE PER CENT OF WATER BOTTOMS AT EQUILIBRIUM
VERSUS ADDITIVE CONCENTRATION IN FUEL

80° F



ADDITIVE CONCENTRATION IN FUEL AFTER EQUILIBRIUM, PER CENT

ADDITIVE PER CENT OF WATER BOTTOMS AFTER EQUILIBRIUM
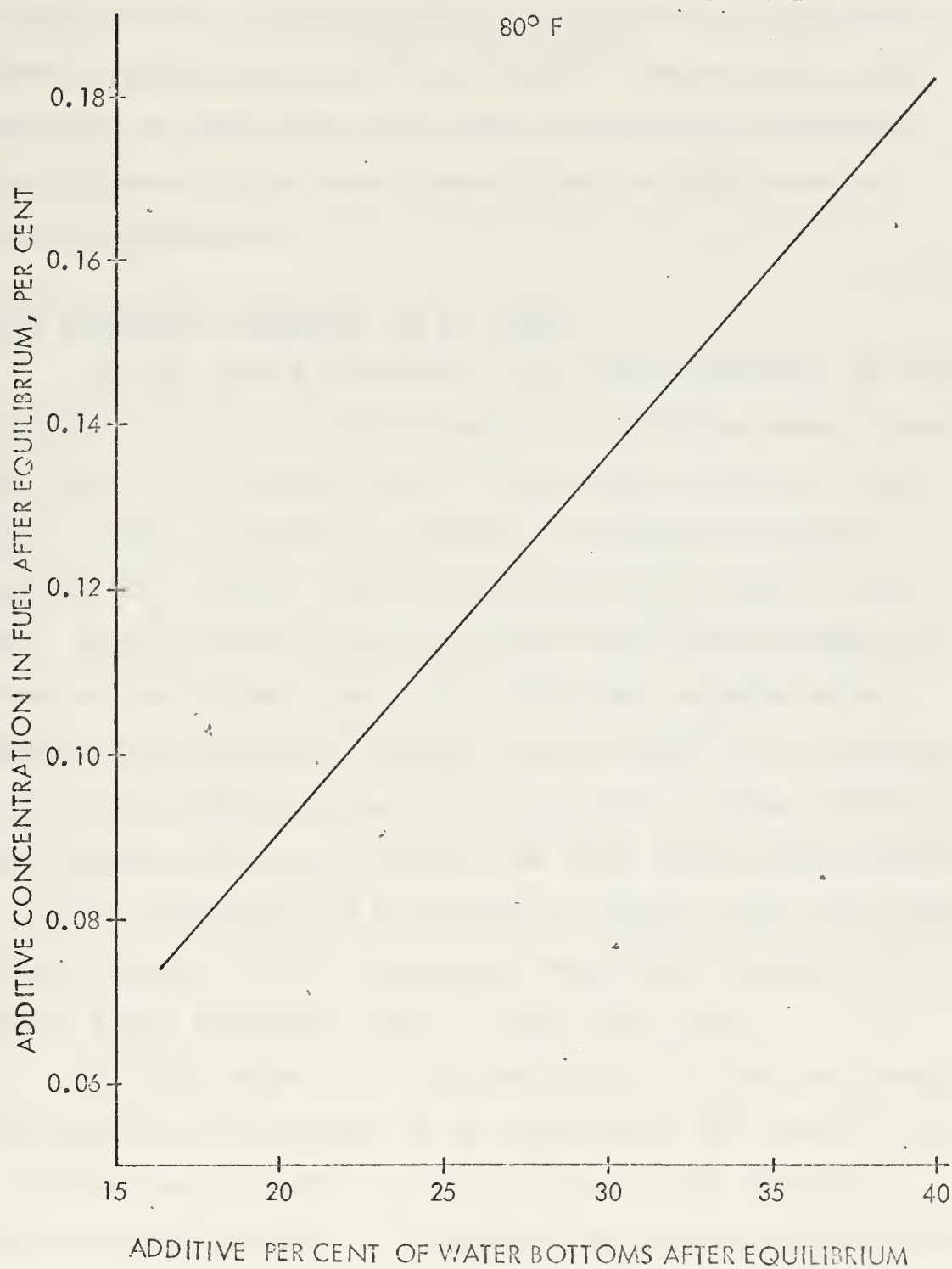
water phase promptly kills new microbial growths before they can multiply in addition to controlling existing slime growths or fungal mats. A lethal mixture of additive in water requires a concentration of 15 per cent.[12] Fortunately, this percentage is well below the normal percentage of additive which migrates to the water phase, thus assuring constant biocidal protection.

## Icing Inhibitor Injection in Jet Fuel

As was stated previously, the icing inhibitor in use is highly soluble in JP4 and remains in solution once it has been added. If the additive is to be injected into a shore tank of JP4, the product is normally circulated through a pump and the additive added incrementally up stream of the pump. Some refineries have facilities for line blending upstream of the product pump, and sufficient turbulence is created in the pump and through the remaining line to insure satisfactory mixing by the time the product reaches the ship. Line blending of icing inhibitor not only permits the refiner to add any percentage of the additive desired, but also saves storage capacity since contractors may obtain product with or without icing inhibitor from the same shore tank.

At this point it is appropriate to discuss the reason for requiring the additive to be injected in JP4 which is to be transported by vessel, vice injection at the discharge port or at the airfield. The demand for and the distribution of JP4 is great. Large demands from activities all over the

world require careful distribution planning. Even with the most sophisticated planning techniques, it is not uncommon for vessels to be diverted to a different discharge port than the one specified at the time of loading. Since it would be too costly to install icing inhibitor injection equipment at every discharge port, each vessel must carry ready-to-use product in order to maintain flexibility. To install an injection system aboard each ship would be costly and wasteful since clean product ships carry a variety of products, and increased equipment weight would reduce the pay load, to say nothing of the problem of obtaining and storing the additive aboard the vessel. The fact that such large quantities of jet fuel are contracted for is another factor. Undoubtedly, the additional cost of icing inhibitor delivered to one refinery location for jet fuel under a large contract is much lower than if the inhibitor were required to be delivered and stored at discharge ports or airfields throughout the world. It would be most desirable if icing inhibitor were available at each location; however, high cost equipment and transportation charges make this arrangement prohibitive. Some activities do have injection equipment but if flexibility is to be maintained, product must be purchased in the ready-to-use form.

# CHAPTER IV

## TEST METHODS FOR THE ADDITIVE AND
## LABORATORY PROCEDURES

### Introduction

The Department of Defense has approved two methods for determining the icing inhibitor content of jet fuel. Both methods are acceptable when the icing inhibitor concentrations are in the range 0.05 to 0.20 volume per cent.

### Refractometer Method

The most recent method to be accepted is the differential refractometer method. The test consists of removing the ethylene glycol monomethyl ether and glycerin from the hydrocarbon fuel by extraction with water. The amount of icing inhibitor in the extract is determined by measuring the difference between its refractive index and that of the water used in making the extraction. Federal Test Method 5340, dated 1 July 1965, describes the procedure in detail and is included as Appendix C.

### Potassium Dichromate-Acid Method

An alternate method to determine the icing inhibitor concentration in a hydrocarbon fuel is described in Federal Test Method 5327.3, dated 1 July 1965. This method was the first to be accepted by the military and was used exclusively in procurement inspections until early 1966. The author

24

selected this method of determination for the thesis tests
described in Chapter V. The glassware and reagents were easily
obtained. Many petroleum testing laboratories, both mili-
tary and commercial, continue to use this test since it is
considered the more reliable of the two. This method also
requires the extraction of the icing inhibitor with water.
The water solution is allowed to react with an excess of
standard potassium dichromate solution in the presence of
sulfuric acid and the excess dichromate is determined idometri-
cally. A copy of this test method is included as Appendix D.

Reagents

The reagents used are listed in Appendix D, paragraph
4. The required solutions were prepared in accordance with
the test method, using accepted laboratory practices. The
sodium thiosulfate solution was standardized weekly.

Apparatus

A list of the required apparatus may be found in Ap-
pendix D, paragraph 3. For ease of operation the following
pieces of equipment were substituted for those listed in the
test method.

1.  Two, 1 gallon glass bottles on an elevated stand were
    used to refill two, 50 milliliter automatic zero
    burets. These bottles contained the potassium dich-
    romate and sodium thiosulfate standard solutions.

2.  Two, 25 milliliter pipets were used. One was used

exclusively for JP4 and the other exclusively for distilled water.

3. A 250 milliliter iodine flask was used vice a 500 milliliter iodine flask since the 500 milliliter flasks were not readily available.

## Specimens

1. Jet Fuel

Approximately 20 gallons of JP4 were used in the laboratory tests. An analysis of the fuel used may be found in Chapter V, page 44. The fuel obtained had not previously been treated with any icing inhibitor.

2. Icing Inhibitor

One gallon of icing inhibitor meeting military specifications was obtained for use in the laboratory experiments. The results of several tests run by a commercial laboratory on the tank from which the gallon sample was taken are listed on page 27.

| Test | Specification Requirement | Sample Results |
|---|---|---|
| Acid number, mg. KOH/gm. | 0.09 Max. | 0.06 |
| Glycerol, Wt.% | 0.36-0.44 Limits | 0.37 |
| Color, platinum cobalt | 20 Max. | Lighter than 20 |
| pH of 25% solution in water at $25° \pm 2°$C | 6.0 to 7.0 Limits | 6-7 |
| Refractive index, (25°C) | 1.4000-1.4010 Limits | 1.4010 |
| Specific gravity (20°/20°C) | 0.965-0.969 Limits | 0.967 |
| Water, % Wt. | 0.2 Max. | 0.08 |

3. Sea Water

Sea Water used in the experiments was prepared by mix-ing tap water with synthetic sea salts purchased from Aquar-ium Systems Incorporated, 1450 East 289th Street, Wickliffe, Ohio, under the trade name of "Instant Ocean."

"F" Factor Determination

An "F" factor determination must be made on each new blend of icing inhibitor used. The factor "F" is the milli-liters of methyl cellosolve-glycerin per milli-equivalent of potassium dichromate and is determined as follows. Five milliliters of a 0.1 per cent methyl-cellosolve glycerin solu-tion were transferred to a pyrex test tube. Ten milliliters of .2N potassium dichromate were added from a buret, and the test tube was placed in an ice bath. After allowing the solution to cool, 5 milliliters of concentrated sulfuric acid were added. The acid was added very slowly, and the test tube

was continually agitated in the ice bath to insure that
thorough mixing occured and that the temperature of the solu-
tion did not rise significantly. After the acid had been
added, agitation was continued for approximately one minute
after which the test tube was placed in a bath of boiling
water for exactly 10 minutes. The test tube was then returned
to the ice bath until the contents had cooled below room tem-
perature. The contents were then transferred to a 250 milli-
liter iodine flask. The test tube was washed 4 times with 5
milliliter portions of distilled water and the washings added
to the flask. Approximately 3 grams of potassium iodide were
added to the contents in the flask. Care was taken to insure
that any iodine vapor which formed was kept in the flask.
The titration of the solution was commenced, adding sodium
thiosulfate to the flask by buret while constantly swirling
it until the brown solution turned to a yellowish-green. Two
milliliters of starch indicator solution were then added and
the titration was slowly continued until the color changed
sharply from dark blue to light bluish-green. The milli-
liters of thiosulfate required were recorded. The "F" factor
was determined as follows:

$$F = \frac{B}{(V_d N_d) - (V_t N_t)}$$

where B = milliliters of methyl cellosolve-glycerin in
aliquot of standard solution analyzed.

$V_d$ = milliliters potassium dichromate

$N_d$ = normality of potassium dichromate

$V_t$ = milliliters sodium thiosulfate

$N_t$ = normality of sodium thiosulfate

The icing inhibitor used in the thesis tests had the "F" factor listed below based on three determinations yielding the same result to three significant figures.

B = 0.00500

$V_d$ = 10.00

$N_d$ = 0.200

$V_t$ = 14.20

$N_t$ = 0.100

$$F = \frac{0.00500}{(0.200)\ (10.00) - (14.20)(0.100)} = 0.00862$$

In the initial determination of the "F" factor, which was the author's first experience with the test, three samples were run simultaneously, each step being performed on the three samples in succession. The three values of "F" increased for each successive sample. Results of various sets of three tests run on a 0.1 per cent solution of the additive in water are shown below.

Milliliters of Sodium Thiosulfate Required
in Four Sets of Tests

|  | Set 1 | Set 2 | Set 3 | Set 4 |
|---|---|---|---|---|
| Sample 1 | 13.75 | 13.85 | 13.90 | 13.85 |
| Sample 2 | 13.85 | 14.00 | 13.95 | 13.90 |
| Sample 3 | 14.00 | 14.05 | 14.10 | 14.05 |

After many timed experiments it was concluded that time was indeed a factor between the addition of the acid and the placement of the solution into the boiling water bath. The solution which received the acid first, even though it remained in the ice bath, required less thiosulfate, indicating that the oxidation process was taking place during this period. In order to solve this problem tests were run, one at a time, through the entire process, insuring that each solution was subjected to the same time interval in each step of the test. Several sets of three tests were run on different solutions and the "F" values on each solution were the same to three significant figures. All following tests were, therefore, run in this manner.

## Analysis of the Fuel

Twenty-five milliliters of the test fuel and 25 milliliters of distilled water were transferred by pipet into a dry 125 milliliter separatory funnel. The separatory funnel was shaken vigorously for 2 minutes. After the water and fuel had separated, the water layer which had extracted the additive was drained into a 50 milliliter Erlenmeyer Flask. Five milliliters of this solution were then transferred to a test tube by means of a pipet.

The test method from this point is exactly as that described in the determination of the "F" factor. The milliliters of sodium thiosulfate required to reach the end point were used to determine the icing inhibitor concentration

in the fuel as follows:

$$\text{Per Cent Concentration} = \frac{100 \ F \left[ (V_d N_d) - (V_t)(N_t) \right]}{AS}$$

Where A = aliquot fraction of water extract used

S = milliliters of hydrocarbon fuel sample

Other symbols are identified under "F" factor determination.

Care was taken to insure that the end point was not passed. Once the end point is reached, any quantity of thio-sulfate may be added to the solution without a color change occurring. As the end point was approached, one drop of thio-sulfate at a time was added in order to prevent inadvertently passing the end point.

## Blank Determination

A blank determination was performed prior to any additive treatment in order to determine components inherent in the fuel which would react during the test and provide misleading results. The same method is used as for a fuel containing icing inhibitor. Three determinations were made, all of which yielded the same result to three significant places.

$$\text{Blank Value} = \frac{100 \ F \left[ (V_d N_d) - (V_t N_t) \right]}{AS}$$

$F = .00862$

$V_d = 10.00$

$N_d = 0.200$

$$V_t = 19.50$$

$$N_t = 0.100$$

$$A = \frac{5.00}{25.00}$$

$$S = 25.00$$

Blank value $= \dfrac{100(.00862)[(10.00)(0.200)-(19.50)(0.100)]}{\frac{5.00}{25.00} \times 25.00} =$

$$0.009$$

The blank determination was subtracted from each test result in order to obtain the actual icing inhibitor concentration in the fuel.

$V_t = 19.50$

$N_t = 0.100$

$A = \dfrac{5.00}{25.00}$

$S = 25.00$

$$\text{Blank value} = \dfrac{100(.00862)[(10.00)(0.200)-(19.50)(0.100)]}{\dfrac{5.00}{25.00} \times 25.00} =$$

0.009

The blank determination was subtracted from each test result in order to obtain the actual icing inhibitor concentration in the fuel.

# CHAPTER V

## LABORATORY TESTS

### Purposes

Laboratory tests were conducted for the following purposes:

1. To determine if physical test results would confirm mathematical predictions of additive concentration in fuel and sea water mixtures, based upon available data for the partition coefficient of the anti-icing additive.

2. To perform tests which would indicate if additive equilibrium could be established in the fuel and water phases by the time a tanker completed loading.

3. To investigate the effect that temperature changes have on additive equilibrium concentration in mixtures of fuel and sea water.

4. To determine if sea water in the ship's tanks would have any effect on the quality of the jet fuel.

### Confirmation of Mathematical Predictions

In order to determine if additive concentrations at equilibrium could be predicted from available partition coefficients, two groups of laboratory tests were run. All tests were performed at room temperature unless otherwise specified. Prior to running the first group of tests, the fuel to be

33

used was saturated with sea water by agitation in a volume-
tric flask.  Care was taken to insure that no free water was
transferred to the test flask along with the saturated fuel.
Enough fuel was transferred to the test flask to nearly fill
it; however, sufficient space was allowed for the addition
of the additive and sea water.  Icing inhibitor was injected
into the flask by means of a pipet.  The flask was then agi-
tated to mix the additive in the fuel.  Sea water was injected
by means of a syringe followed by enough fuel to bring the
flask to volume.  The flask was again agitated to speed up
the equilibrium process.

The volume of additive expected to migrate to the
water phase was determined mathematically by using the formu-
la derived in Chapter III, page 16 .  The K value used was
220 since the temperature at which the tests were conducted
was approximately $80^{\circ}$ F.  The percentage of additive expected
to remain in the fuel was determined as follows:

$$A_f(\%) = \frac{\left[(A_f)_o - A_w\right] 100}{F}$$

where $(A_f)_o$ = initial volume of additive in fuel

$A_w$ = additive volume in water at equilibrium

$F$ = fuel volume

Table 1 indicates the results of the tests conducted.

TABLE 1

LABORATORY MEASUREMENT OF ADDITIVE CONCENTRATION IN
SATURATED FUEL VERSUS MATHEMATICAL PREDICTION

| Component Quantities in Milliliters | | | Per Cent | Per Cent |
|---|---|---|---|---|
| Saturated Fuel | Additive | Sea Water | Lab. Measure of Additive Concen. in Fuel at Equilib. | Mathematical Prediction |
| 998.0 | 1.5 | 0.5 | 0.129 | 0.130 |
| 997.3 | 1.7 | 1.0 | 0.132 | 0.130 |
| 996.2 | 1.8 | 2.0 | 0.114 | 0.114 |
| 996.6 | 1.8 | 1.6 | 0.123 | 0.122 |

Since the additive was mixed into the fuel prior to
the addition of water, test results after water contact in-
dicated a decreasing additive content in the fuel until equi-
librium was established. The flasks were periodically agi-
tated and tests were conducted until the same test results
were continually obtained, indicating that equilibrium was
established. Even though only four tests were conducted, it
is considered significant that most of the results were with-
in 0.001 per cent concentration of the predicted value.

The second group of tests were conducted in a similar
manner to the first group; however, the fuel used was not
saturated with sea water. Table 2 indicates the results of
the second group of tests. Table 2 clearly shows that the

## TABLE 2

### LABORATORY MEASUREMENT OF ADDITIVE CONCENTRATION IN FUEL VERSUS MATHEMATICAL PREDICTION

| Component Quantities in Milliliters | | | Per Cent | Per Cent | Per Cent |
|---|---|---|---|---|---|
| Unsaturated Fuel | Additive | Sea Water | Lab. Measure of Additive Concen. in Fuel at Equilib. | Mathematical Prediction | Prediction if 80 ppm Water was Absorbed |
| 99.749 | 0.151 | 0.10 | 0.120 | 0.117 | 0.119 |
| 99.789 | 0.151 | 0.06 | 0.134 | 0.128 | 0.130 |
| 997.41 | 1.750 | 0.84 | 0.150 | 0.139 | 0.141 |
| 998.33 | 1.460 | 0.21 | 0.144 | 0.137 | 0.140 |
| 1996.2 | 3.000 | 0.80 | 0.144 | 0.134 | 0.137 |

mathematical predictions were not confirmed by the tests. The fuel will hold approximately 80 parts per million of water at room temperature.[13] Table 2 also indicates the mathematically predicted concentration, assuming that the fuel absorbed 80 parts per million of the injected water. The laboratory test results are somewhat closer to this revised prediction. The mixtures listed under Table 2 were subjected to much more agitation than those listed under Table 1, and it is believed that the agitation was a factor in the result. The interior of the flasks in the second group of tests were coated with beads of water. It is believed that the dispersion of the water reduced its ability to absorb additive because in some flasks water beads were up above the fuel level, which reduced the water available to absorb additive. Care was taken in agitating the flasks in the first group to insure that the water remained as one phase in the bottom of the flask.

The tests conducted indicate that when a vessel is loaded, the icing inhibitor concentration at equilibrium will very likely be slightly higher than the mathematical prediction. It is concluded, however, that equilibrium concentrations may be easily predicted within the range of the military specification.

## Equilibrium Times

After a vessel has been loaded with cargo it is normally not permitted to leave its berth until laboratory tests

are run on a ship's composite sample to insure that the product meets specification requirements. If a vessel is loaded as the author proposes, fuel will be pumped to the ship containing sufficient icing inhibitor to satisfy the following requirements.

1. An amount which will be absorbed by the ballast residue aboard the vessel.

2. An amount to satisfy the desired icing inhibitor content of the fuel itself after additive absorption in the water bottoms has occurred.

The time required for the additive in the water and in the fuel to reach equilibrium must be taken into consideration. Since anti-icing tests will be run on the ship's composite sample, the rate of attainment of equilibrium for the additive must be known.

Laboratory tests were run on several samples in an effort to determine the time required for equilibrium to be established. Table 3 indicates the results of these tests. Samples were vigorously shaken for approximately five minutes immediately after preparation and randomly throughout the testing period.

It should be noted that the first two samples in Table 3 were prepared by mixing the additive in the fuel prior to the addition of water, while the last two were prepared by mixing the additive in a small quantity of fuel and the water. The balance of the fuel was then added after the

## TABLE 3

### TIME REQUIREMENTS FOR ADDITIVE EQUILIBRIUM TO BE ESTABLISHED IN FUEL AND SEA WATER

| Initial Composition | Additive Concentration in Fuel After Time Specified | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Per Cent | Per Cent | | | | | | |
| Additive Sea Water<br>0.175   0.084 | 5 Min.<br>0.170 | 5 Hrs.<br>0.155 | 17 Hrs.<br>0.150 | 22 Hrs.<br>0.150 | 45 Hrs.<br>0.150 | 6 Days<br>0.151 | 9 Days<br>0.149 |
| Additive Sea Water<br>0.175   0.084 | 1.5 Hrs.<br>0.158 | 18 Hrs.<br>0.150 | 4 Days<br>0.151 | 7 Days<br>0.152 | | | |
| Additive Sea Water*<br>0.146   0.021 | 1 Hr.<br>0.142 | 18 Hrs.<br>0.144 | 66 Hrs.<br>0.144 | 4 Days<br>0.144 | | | |
| Additive Sea Water*<br>0.15   0.05 | 11 Hrs.<br>0.128 | 14 Hrs.<br>0.130 | 20 Hrs.<br>0.129 | 36 Hrs.<br>0.129 | | | |

*Sample was prepared adding sea water and icing inhibitor in approximately 250 milliliters of fuel. Sufficient fuel was then added to bring volume to 1000 milliliters. This accounts for the initial low additive concentration since the additive was migrating from the water phase to the fuel phase.

flask had been agitated. Table 3 indicates the result. In the first two samples the additive was migrating from the fuel to the water phase, while in the last two the migration was taking place in reverse order. The time required for equilibrium was approximately eighteen hours.

It was realized that the means by which the samples in Table 3 were mixed could not be compared with the mixing which would take place on board a ship. In an effort to simulate more closely the mixing that would take place aboard ship another test was conducted. A 10 gallon can was obtained and fuel containing icing inhibitor was siphoned with approximately a 10 foot head through three-sixteenths inch glass tubing and into a pipe which extended from the top to the bottom of the can. Sea water was placed in the bottom of the can so that any fuel entering the can had to pass through the pipe and come in contact with the water. This would be very similar to the mixing process which would occur in a ship. It became evident after commencing the test that the turbulence at the bottom of the can was not similar to that witnessed in loading a ship. Even after a ship's tank is nearly full, product motion may be seen by looking into the tank. In the case of the experiment, no motion could be seen even after one inch of product had been siphoned into the can. The test was continued, however, in order to see what the equilibrium time would be. The can was allowed to remain motionless for approximately two days and the test results shown in Table 4 were obtained during this period.

TABLE 4

TIME REQUIREMENTS FOR ADDITIVE EQUILIBRIUM TO BE
ESTABLISHED IN FUEL AND SEA WATER

Starting Conditions
Additive Concen. in Fuel = 0.175%
Water Volume = 0.120%

| After Time Specified | Concentration In Fuel (Per Cent) |
|---|---|
| 20 Min. | 0.170 |
| 2.7 Hrs. | 0.166 |
| 8.2 Hrs. | 0.163 |
| 19.5 Hrs. | 0.156 |
| 26.7 Hrs. | 0.151 |
| 31.7 Hrs. | 0.150 |
| 44.7 Hrs. | 0.144 |

A device was constructed which would provide a rocking motion to the container. The container was supported in a cradle. A connecting rod moved by a cam attached to a motor shaft on one end and the cradle base on the other provided approximately a 20 degree swing on both sides of vertical. The rate of movement was approximately 40 cycles per minute. The rocking device was turned on and the container was in motion for the remainder of the testing period. The results shown below were obtained during this period.

| After Time Specified | Additive Concentration In Fuel (Per Cent) |
|---|---|
| 3 Hrs. | 0.140 |
| 9 Hrs. | 0.139 |
| 22 Hrs. | 0.134 |
| 50 Hrs. | 0.134 |

The author concluded from these tests that there is a very good possibility that equilibrium will not be established by the time a tanker completes loading. The time required to load a tanker with JP4 is dependent on many factors. An average loading time for a T2 could be expected to be about 15 hours. An anti-icing test result from a ship's composite sample would, therefore, be expected to lie in the range between the initial concentration in the fuel and the calculated concentration at equilibrium. It is, however, possible that the turbulence created in a vessel's tanks will bring the additive much closer to equilibrium than was experienced in the laboratory tests.

Temperature Effects

In order to investigate the effect which could be expected when temperature changes occur as a vessel proceeds from one climate to another, the tests shown in Table 5 were conducted.

In extreme cases the fuel temperature aboard ship might get as low as 35°F. The normal temperature range would be 40°F to 90°F. The tests shown in Table 5 merely indicate that if the fuel undergoes a large decrease in temperature the icing inhibitor content will not be seriously depleted.

## TABLE 5

### ADDITIVE CONCENTRATION IN FUEL AT VARIOUS
### TEMPERATURES

Initial Conditions at Room Temperature after Equilibrium:
Additive Concentration in Fuel = 0.149%,
Water = 0.084%

| Temperature | Time Sample at Specified Temperature | Additive Concentration in Fuel (Per Cent) |
|---|---|---|
| 32°F | 2 Days | 0.125 |
| 32°F | 5 Days | 0.119 |

Initial Conditions at Room Temperature after Equilibrium:
Additive Concentration in Fuel = 0.152%,
Water = 0.084%

| Temperature | Time Sample at Specified Temperature | Additive Concentration in Fuel (Per Cent) |
|---|---|---|
| 32°F | 2 Days | 0.126 |
| 32°F | 5 Days | 0.126 |
| 46°F | 1 Day | 0.142 |
| 46°F | 2 Days | 0.140 |

## Salt Water Effect

Table 6 shows JP4 specification requirements and the
results of tests run on the fuel both before and after sea
water contact. The tests were run by the American Oil Company Laboratory, Sugar Creek, Missouri. Test 1 was run on
a sample taken from the same storage tank that the fuel used
in the laboratory tests was taken. It contained no icing

## TABLE 6

### JP4 SPECIFICATION TEST RESULTS AFTER SEA WATER CONTACT

| Test | Specification Requirements | Test 1 Original Fuel | Test 2 Original Fuel | Test 3 After Sea Water Contact |
|---|---|---|---|---|
| Gravity, °API | 45-57.0 Limits | 54.2 | 54.0 | 53.9 |
| Distillation: | | | | |
| Initial Pt., °F | Report | 129 | 141 | 138 |
| 10% Evap., °F | Report | 184 | 192 | 189 |
| 20% Evap., °F | 290°F Max. | 213 | 219 | 218 |
| 50% Evap., °F | 370°F Max. | 276 | 281 | 280 |
| 90% Evap., °F | 470°F Max. | 416 | 411 | 411 |
| 400°F Point, % Evap. | Report | 88.0 | 87.0 | 87.0 |
| End Point, °F | Report | 485 | 491 | 493 |
| Residue & Loss, vol. % | 1.5 & 1.5 Max. | 1.0 & 1.0 | 1.0 & 1.0 | 1.0 & 1.0 |
| Reid Vapor Press., psi | 2.0-3.0 Limits | 2.9 | 2.8 | 2.8 |
| Doctor Test | Negative | Negative | Negative | Negative |
| Corrosion, CuStrip | 1b Max. | 1A | 1A | 1A |
| Smoke Point, mm. | Report | 27 | 26 | 27 |
| Smoke Volatility Index | 52.0 Min. | 64.0 | 64.1 | 63.5 |
| Existent Gum, mg/100ml. | 7.0 Max. | 0.6 | 0.2 | 0.2 |
| Potential Gum, mg/100ml. | 14.0 Max. | 1.5 | 3.2 | 2.2 |
| Freezing Point, °F | -72 Max. | -90 | <-80 | <-80 |
| Aromatics & Olefins, vol.% | 25.0 & 5.0 Max. | 11.1 & 1.6 | 11.9 & 0.7 | 11.7 & 0.7 |
| Aniline Point, °F | Report | 128.0 | 128.0 | 128.0 |
| Aniline-Gravity Product | 5250 Min. | 6950 | 6920 | 6900 |
| Water Reaction | 1b Max. | 1 | 1 | 1 |
| Sulfur, Tot.wt. % | 0.4 Max. | 0.165 | 0.138 | 0.173 |

## TABLE 6
### (Continued)

| Test | Specification Requirements | Test 1 Original Fuel | Test 2 Original Fuel | Test 3 After Sea Water Contact |
|---|---|---|---|---|
| Thermal Stability: | | | | |
| Pressure Drop, In. Hg. | 3.0 Max. | 0.3 | * | * |
| Deposit | Less than 3 | #1 | * | * |
| Icing Inhibitor (GAFCOL EMG) | 0.10-0.15 Limits | Unknown | 0.006 | 0.141 |
| W.S.I.M. (after San.C) | 70 Min. | 94 | 91 | 99 |
| Particulate Contaminant, mg/gal. | 4.0 Max. | Unknown | 2.1 | 3.2 |
| Anti-Oxidant (AMOCO 535), Lbs./MBbls. | 8.4 Max. | 1.25 | 1.25 | 1.25 |
| Metal Deactivator (AMOCO 522), Lbs./MBbls. | 2.0 Max. | 1.25 | 1.25 | 1.25 |
| Corrosion Inhibitor, Lbs./MBbls. | 4.0-4.5 Limits | None | None | None |

*Insufficient sample quantity to perform test.

inhibitor. Test 2 was run on a sample of the fuel which had not been used in any tests but had been retained in a 5 gallon container during the testing period. This sample should have produced test results duplicate to Test 1. Test 3 was run on the fuel which contained icing inhibitor and which had been exposed to salt water for a period of approximately 24 days. During this period the mixture was intermittently agitated by use of the rocking device.

The results indicate that fuel contact with salt water will have no significant effect on the quality of the fuel.

Summary

The following conclusions were drawn from the laboratory tests.

1. If the quantities of fuel, icing inhibitor and water are known in a mixture, the icing inhibitor content of the fuel at equilibrium may be reasonably predicted.

2. In order to determine if equilibrium will be reached by the time a tanker is loaded, tests must be performed actually using a vessel. In any case, after loading has been completed, an icing inhibitor test will indicate if the actual icing inhibitor concentration is within range to meet the desired concentration at equilibrium.

3. The icing inhibitor content of the fuel will not be seriously depleted by temperature changes experienced

while aboard the tanker. It should be noted, however, that in cold weather the additive concentration at equilibrium will be lower than that predicted using a partitioning coefficient of 220. A good estimate of the partitioning coefficient to use when the fuel temperature is not in the 70-80°F range may be found in Chapter III, page 19.

4. The small quantity of salt water remaining aboard a tanker will have no significant effect on the quality of the fuel.

# CHAPTER VI
## COMPUTER SIMULATIONS

### Introduction

The calculations required to predict additive equilibrium concentrations mathematically are not difficult. They are, however, time consuming since at least 26 separate calculations are required for each tanker. A computer program was written in order to provide a rapid means of determining simulation results. The program also allows the operator to estimate the water quantity remaining aboard the vessel and to see the resulting additive concentration in each compartment due to his estimate. An economic analysis was incorporated into the program comparing the cost of drying tanks with the cost of increasing the additive content in the fuel. Another purpose of the program was to determine a procedure for calculating the additional icing inhibitor required, which could be simplified and done by hand calculation. Appendix E defines the input variables and symbols used in the program. The program itself is included along with input and output examples.

### Program Operations

The following input data are required by the program.

1. The desired icing inhibitor content of the total cargo after equilibrium has been established.

43

2. The number of wing tanks the vessel has on each side.

3. The number of center tanks the vessel has.

4. The additional cost per gallon of product for in-
   creasing the icing inhibitor content above the speci-
   fication maximum of 0.15 per cent. The condition
   which warrants a cost increase may seem somewhat un-
   realistic, yet it was taken from a past military jet
   fuel contract.[13] For example, if the icing inhibitor
   concentration is required above 0.150 per cent, the
   additional cost per gallon of product is the same
   regardless of whether the concentration is 0.155 per
   cent or 0.180 per cent. It is anticipated that if
   the method of loading described in this thesis became
   common, cost increases would be established for in-
   cremental increases in additive concentration. The
   method of determining the cost for additional inhibi-
   tor was used only because it represented real life
   conditions which existed at the time the thesis was
   written.

5. The hourly cost to operate the type tanker being
   simulated. The costs used in this thesis were ob-
   tained from the Military Sea Transportation Service,
   Washington, D.C.

6. An estimate of the amount of water which will remain
   aboard the tanker after it has been stripped dry.
   This data is optional. If it is omitted, the program

calculates the equilibrium concentrations with the
actual water input data supplied. If an estimate is
made, the estimated water is used to determine the
icing inhibitor concentration of the fuel supplied
to the ship. The average equilibrium concentration
is calculated on the basis of actual water in the
tanks and the effect of a bad estimate may be eval-
uated.

7. The actual fuel quantity to be loaded in each ship's
   tank.

8. The actual water quantities which exist in each
   ship's tank.

The icing inhibitor concentration supplied in the fuel
to the ship is determined in the following manner. A pre-
selected average additive absorption percentage is set by the
desired average additive concentration at equilibrium. This
percentage is multiplied by the total actual water on board
to determine the average amount of additive which will be ab-
sorbed by the water. The desired additive concentration at
equilibrium is multiplied by the total barrels of fuel loaded
to determine the barrels of additive required in the fuel at
equilibrium. The two icing inhibitor quantities calculated
are added and divided by the total fuel. This figure multi-
plied by 100 is the additive percentage to be injected into
the fuel pumped to the vessel.

The actual additive concentration in each ship's tank

is then calculated by the formula derived in Chapter III.
Each tank's fuel quantity is then multiplied by its respective
additive concentration at equilibrium. The barrels of addi-
tive in each tank are summed and divided by the total fuel
in order to determine the average cargo additive concentration
at equilibrium.

The economic analysis simply compares the cost of addi-
tional additive with the cost incurred at various drying times
and provides the difference either in dollars saved or addi-
tional cost incurred.

## Program Data

The data used in the computer simulations were ob-
tained from several sources. The fuel quantities were taken
from past T2 tanker loading reports supplied by the Military
Sea Transportation Service, Washington, D.C.

The quantity of water which remains aboard a tanker
after the vessel has been stripped dry is dependent upon
several factors. The condition of the pipelines, the condi-
tion of the stripping pump, and the trim of the vessel all
affect the amount of water which may be removed. The author's
experience in loading tankers provided him with a good esti-
mate as to the average amount of water remaining in a T2. In
order to use the best possible data, approximately 30 ques-
tionnaires were sent to operating tankers. Eight replies
were received. The replies came from a number of sources,
including first officers, shore pumpmen, Captains, and military

petroleum inspectors. None of the estimates received differed greatly from any other. Below is the average estimated water quantity per tank taken from the 8 replies received.

### Figures are in U.S. Gallons

| Tank No. | Starboard | Center | Port |
|----------|-----------|--------|------|
| 1 | 13 | -- | 13 |
| 2 | 13 | 36 | 13 |
| 3 | 13 | 19 | 13 |
| 4 | 18 | 42 | 18 |
| 5 | 16 | 24 | 16 |
| 6 | 17 | 47 | 17 |
| 7 | 22 | 28 | 22 |
| 8 | 21 | 59 | 21 |
| 9 | 34 | 36 | 34 |

Various computer simulations were run using the water quantities above. The fuel quantities used were taken from actual tanker loading reports. All of the figures referred to below are reductions of actual computer output pages. The icing inhibitor concentrations shown on the vessel diagrams are concentrations in the fuel at equilibrium. All fuel and water quantities shown on the figures are in barrels. The first simulation was performed using a desired additive concentration in the fuel at equilibrium of 0.14 per cent. Figure 7a indicates the average additive concentration at equilibrium to be 0.139 per cent. It is significant that fuel with an additive concentration of only 0.144 per cent had to be loaded aboard the ship to attain the desired result. Figures 8a, 9a, and 10a use the same fuel and water quantities;

however, water estimates are made. In Figure 8a, it was esti-
mated that 50 per cent less water was aboard the ship than
actually existed. The average additive concentration in
fuel at equilibrium dropped only 0.002 per cent to 0.137.
In Figure 9a, fifty per cent more water was estimated aboard
the ship than actually existed. The final average concentra-
tion was 0.140 per cent and the percentage of additive re-
quired to be added in the fuel pumped to the ship still did
not exceed the maximum specification limit. In Figure 10a,
one hundred per cent more water was estimated than existed.
The results were still within specification limits. In all
cases, the vessels could have been loaded without drying
tanks. The dollars saved appear on the economic analysis
data sheets, Figures 7b, 8b, 9b, and 10b.

Figure 11a shows the result of input data requiring
a 0.15 per cent average concentration of icing inhibitor in
the fuel at equilibrium. In this case, the concentration of
additive in the fuel pumped to the vessel exceeds the maxi-
mum specification limit of 0.150 per cent. The cost for the
additional additive is, therefore, taken into consideration
in the economic analysis, Figure 11b. It would be less ex-
pensive to load this vessel by the new method only if the
drying time was known to be greater than 12.6 hours.

## Summary

The computer simulations indicate that there is a very
good possibility that T2 tankers may be loaded without drying

tanks and without any additional cost for icing inhibitor as long as the icing inhibitor concentration in the fuel pumped to the vessel is between 0.135 and 0.150 per cent.

Even if the icing inhibitor concentration in the fuel pumped to the vessel must be greater than 0.150 per cent, it seems likely that increasing the icing inhibitor content in the fuel will be more economical than drying a vessel's tanks.

A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 136635.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 14.8
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.139 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.144 PERCENT MUST BE LOADED ABOARD THE VESSEL.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK.
(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF ICING INHIBITOR)

| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|
| | 3092.0 | 3894.0 | 3978.0 | 3962.0 | 3975.0 | 3981.0 | 3944.0 | 3592.0 | STBD |
| | 9412.0 | 9218.0 | 9194.0 | 9244.0 | 5913.0 | 9222.0 | 9178.0 | 9048.0 | CENTER |
| | 3080.0 | 3842.0 | 3983.0 | 3984.0 | 3989.0 | 3984.0 | 3947.0 | 3571.0 | PORT |

2505.0
2499.0

THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE
RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION.

| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.3 0.139 | 0.3 0.140 | 0.4 0.139 | 0.4 0.139 | 0.4 0.139 | 0.5 0.138 | 0.5 0.138 | 0.8 0.134 | STBD |
| | 0.9 0.139 | 0.4 0.141 | 1.0 0.139 | 0.6 0.141 | 1.1 0.135 | 0.7 0.140 | 1.4 0.137 | 0.9 0.139 | CENTER |
| | 0.3 0.139 | 0.3 0.140 | 0.4 0.139 | 0.4 0.139 | 0.4 0.139 | 0.5 0.138 | 0.5 0.138 | 0.8 0.134 | PORT |

0.3 0.138
0.3 0.138
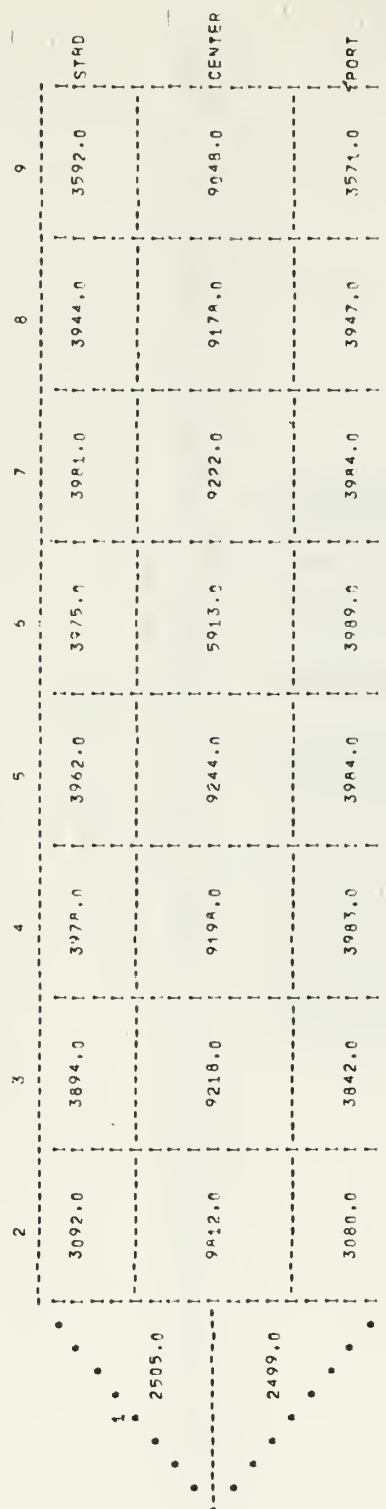
Figure 7a - A Simulation of Icing Inhibitor Concentrations in JP4 Aboard a T2 Tanker

ECONOMIC ANALYSIS
----------------

COST TO DRY SHIP = $ 168.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.144. SINCE THIS CONCENTRATION IS NOT ABOVE THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.139 PERCENT. NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE SAVED.

```
IF DRYING TIME IS  4 HOURS, $   672. WILL BE SAVED.
IF DRYING TIME IS  8 HOURS, $  1344. WILL BE SAVED.
IF DRYING TIME IS 12 HOURS, $  2016. WILL BE SAVED.
IF DRYING TIME IS 16 HOURS, $  2688. WILL BE SAVED.
IF DRYING TIME IS 24 HOURS, $  4032. WILL BE SAVED.
IF DRYING TIME IS 36 HOURS, $  6048. WILL BE SAVED.
IF DRYING TIME IS 48 HOURS, $  8064. WILL BE SAVED.
IF DRYING TIME IS 60 HOURS, $ 10080. WILL BE SAVED.
IF DRYING TIME IS 72 HOURS, $ 12096. WILL BE SAVED.
```

Figure 7b - Economic Analysis

A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 136635.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 14.8.
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.137 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.142 PERCENT MUST BE LOADED ABOARD THE VESSEL.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK.
(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF ICING INHIBITOR)

| 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|
| 3892.0 | 3894.0 | 3978.0 | 3942.0 | 3975.0 | 3981.0 | 3944.0 | 7592.0 | STBD |
| 9812.0 | 9218.0 | 9198.0 | 9244.0 | 5993.0 | 9222.0 | 9978.0 | 998.0 | CENTER |
| 3060.0 | 3942.0 | 3987.0 | 3984.0 | 3989.0 | 7944.0 | 3947.0 | 7571.0 | PORT |

2505.0

2499.0

THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION. WATER ESTIMATE WAS 7.4 BARRELS.

| 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|
| 0.3 / 0.137 | 0.3 / 0.138 | 0.4 / 0.137 | 0.4 / 0.138 | 0.4 / 0.137 | 0.5 / 0.136 | 0.5 / 0.136 | 0.8 / 0.132 | STBD |
| 0.9 / 0.134 | 0.4 / 0.140 | 1.0 / 0.137 | 0.6 / 0.139 | 1.1 / 0.134 | 0.7 / 0.138 | 1.4 / 0.135 | 0.9 / 0.138 | CENTER |
| 0.3 / 0.137 | 0.3 / 0.137 | 0.4 / 0.137 | 0.4 / 0.137 | 0.4 / 0.137 | 0.5 / 0.136 | 0.5 / 0.136 | 0.8 / 0.132 | PORT |

0.3 / 0.136

0.3 / 0.136

Figure 8a - A Simulation Using a Water Estimate of 50% Less Than Actual Water

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                    ECONOMIC ANALYSIS
                    -----------------

          COST TO DRY SHIP = $ 168.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.142. SINCE THIS CONCENTRATION IS NOT ABOVE
THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL
TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.137 PERCENT, NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE
SAVED.

IF DRYING TIME IS  4 HOURS, $   672. WILL BE SAVED.
IF DRYING TIME IS  8 HOURS, $  1344. WILL BE SAVED.
IF DRYING TIME IS 12 HOURS, $  2016. WILL BE SAVED.
IF DRYING TIME IS 16 HOURS, $  2688. WILL BE SAVED.
IF DRYING TIME IS 24 HOURS, $  4032. WILL BE SAVED.
IF DRYING TIME IS 36 HOURS, $  6048. WILL BE SAVED.
IF DRYING TIME IS 48 HOURS, $  8064. WILL BE SAVED.
IF DRYING TIME IS 60 HOURS, $ 10080. WILL BE SAVED.
IF DRYING TIME IS 72 HOURS, $ 12096. WILL BE SAVED.
```

Figure 8b - Economic Analysis

Figure 9a - A Simulation Using a Water Estimate of 50% More Than Actual Water

```
                    ECONOMIC ANALYSIS
                    -----------------

          COST TO DRY SHIP = $ 168.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.146.  SINCE THIS CONCENTRATION IS NOT ABOVE
THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL
TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.140 PERCENT.  NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE
SAVED.


      IF DRYING TIME IS  4 HOURS, $   672. WILL BE SAVED.
      IF DRYING TIME IS  8 HOURS, $  1344. WILL BE SAVED.
      IF DRYING TIME IS 12 HOURS, $  2016. WILL BE SAVED.
      IF DRYING TIME IS 16 HOURS, $  2688. WILL BE SAVED.
      IF DRYING TIME IS 24 HOURS, $  4032. WILL BE SAVED.
      IF DRYING TIME IS 36 HOURS, $  6048. WILL BE SAVED.
      IF DRYING TIME IS 48 HOURS, $  8064. WILL BE SAVED.
      IF DRYING TIME IS 60 HOURS, $ 10080. WILL BE SAVED.
      IF DRYING TIME IS 72 HOURS, $ 12096. WILL BE SAVED.
```

Figure 9b - Economic Analysis

A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.

4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 14.8
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.142
PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.148 PERCENT MUST BE LOADED ABOARD THE VESSEL.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK.
(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF ICING INHIBITOR)

THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE
RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION.
WATER ESTIMATE WAS 29.6 BARRELS.

Figure 10a - A Simulation Using a Water Estimate of 100% More Than Actual Water

ECONOMIC ANALYSIS
----------------

COST TO DRY SHIP = $ 158.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.148. SINCE THIS CONCENTRATION IS NOT ABOVE
THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT. THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL
TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.142 PERCENT. NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE
SAVED.

IF DRYING TIME IS  4 HOURS.$   672. WILL BE SAVED.
IF DRYING TIME IS  8 HOURS.$  1344. WILL BE SAVED.
IF DRYING TIME IS 12 HOURS.$  2016. WILL BE SAVED.
IF DRYING TIME IS 16 HOURS.$  2688. WILL BE SAVED.
IF DRYING TIME IS 24 HOURS.$  4032. WILL BE SAVED.
IF DRYING TIME IS 36 HOURS.$  6048. WILL BE SAVED.
IF DRYING TIME IS 48 HOURS.$  8064. WILL BE SAVED.
IF DRYING TIME IS 60 HOURS.$ 10080. WILL BE SAVED.
IF DRYING TIME IS 72 HOURS.$ 12096. WILL BE SAVED.

Figure 10b - Economic Analysis

A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A T-2 TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.150 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
4. TOTAL BARRELS OF PRODUCT LOADED = 126304.
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.149 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.153 PERCENT MUST BE LOADED ABOARD THE VESSEL.

TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 8.4.

THE DIAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK.
(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF ICING INHIBITOR)

|  | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|
|  | 3007.0 | 3865.0 | 3998.0 | 4023.0 | 4005.0 | 4004.0 | 3944.0 | 3915.0 | STBD |
|  | 3822.0 | 9163.0 | 9200.0 | 9147.0 | 5897.0 | 9227.0 | 4813.0 | 9043.0 | CENTER |
|  | 3082.0 | 3880.0 | 3997.0 | 3989.0 | 3984.0 | 4011.0 | 3959.0 | 3590.0 | PORT |

2499.0
2493.0

THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TANK AND THE RESULTING ICING INHIBITOR CONCENTRATION IN PERCENT BY VOLUME AFTER WATER EXTRACTION.
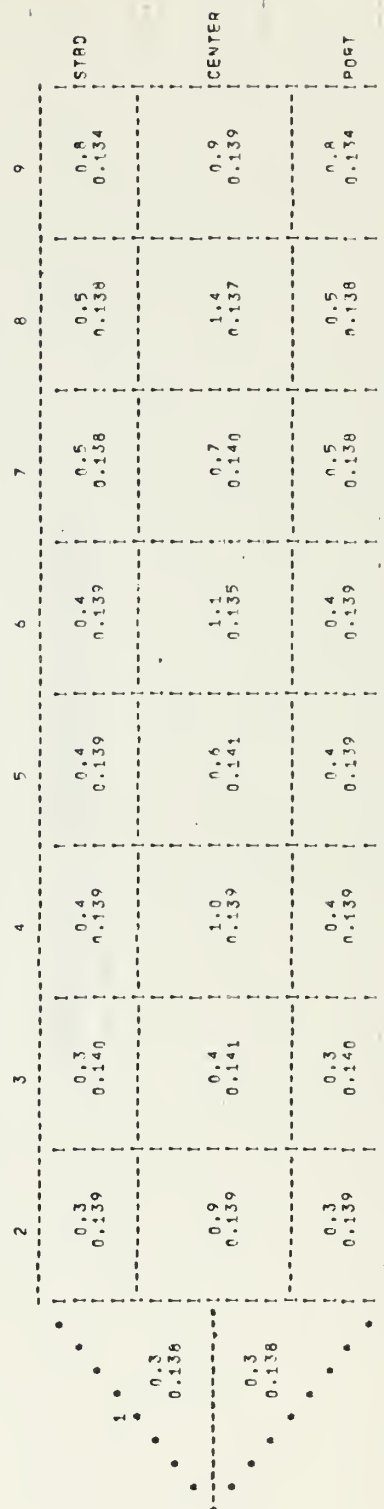
|  | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|
|  | 0.1 / 0.150 | 0.1 / 0.151 | 0.2 / 0.149 | 0.2 / 0.149 | 0.2 / 0.149 | 0.2 / 0.149 | 0.1 / 0.151 | 0.1 / 0.151 | STBD |
|  | 0.6 / 0.145 | 0.7 / 0.149 | 0.7 / 0.149 | 0.6 / 0.149 | 0.6 / 0.147 | 0.6 / 0.149 | 0.7 / 0.146 | 0.7 / 0.149 | CENTER |
|  | 0.1 / 0.150 | 0.1 / 0.151 | 0.2 / 0.149 | 0.2 / 0.149 | 0.2 / 0.149 | 0.2 / 0.149 | 0.1 / 0.151 | 0.1 / 0.151 | PORT |

0.2 / 0.148
0.2 / 0.148
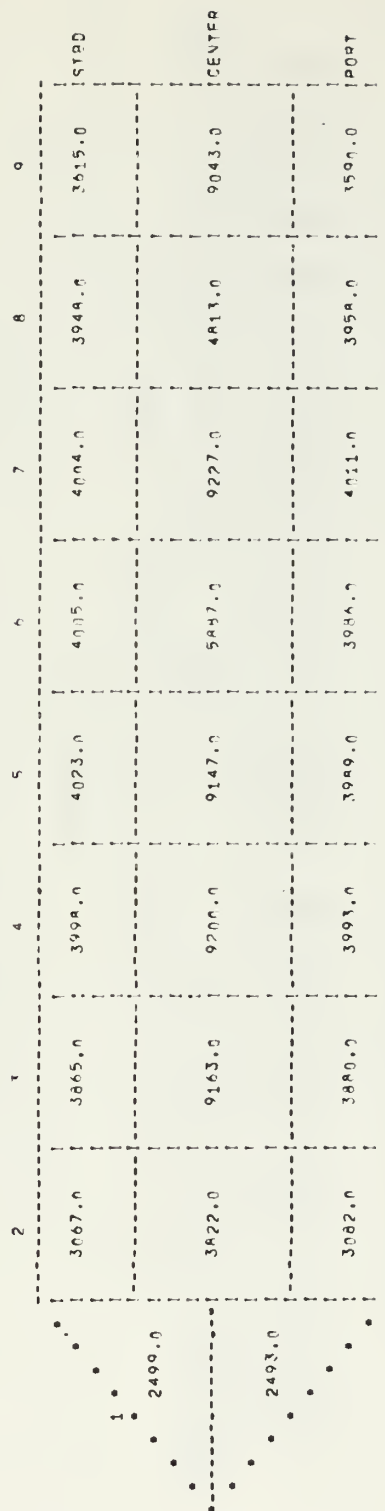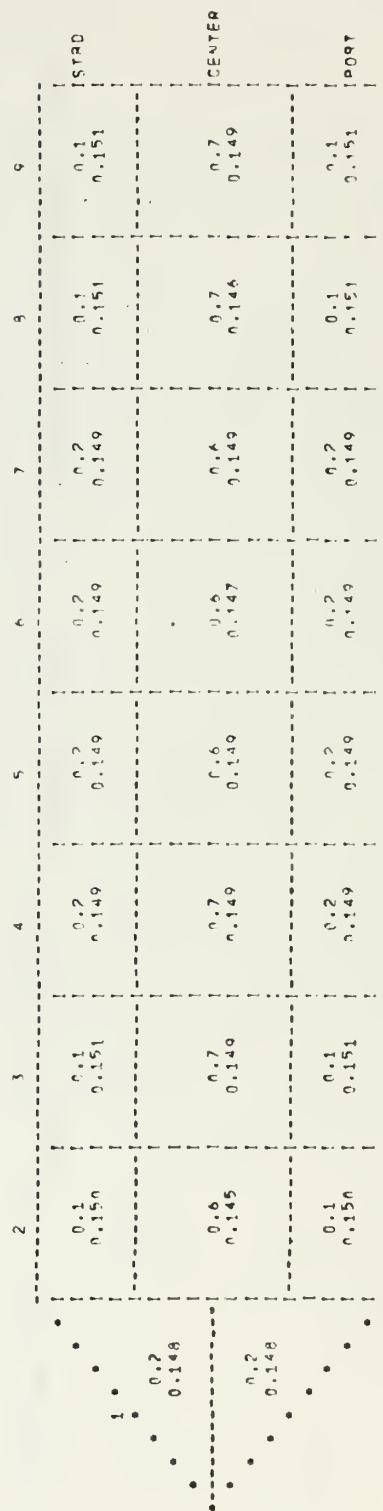
Figure 11a - Simulation Requiring an Additive Equilibrium Concentration of 0.15%

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                              ECONOMIC ANALYSIS
                              ----------------

                    COST TO DRY SHIP = $ 168.00 PER HOUR.

        COST TO INCREASE ICING INHIBITOR CONCENTRATION OF THIS CARGO ABOVE 0.15 PERCENT = $ 2121.97

IF DRYING TIME IS  4 HOURS.AN ADDITIONAL COST OF $ 1450. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.
IF DRYING TIME IS  8 HOURS.AN ADDITIONAL COST OF $  778. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.
IF DRYING TIME IS 12 HOURS.AN ADDITIONAL COST OF $  106. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.
IF DRYING TIME IS 16 HOURS.$  566. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.
IF DRYING TIME IS 24 HOURS.$ 1910. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.
IF DRYING TIME IS 36 HOURS.$ 3926. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.
IF DRYING TIME IS 48 HOURS.$ 5942. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.
IF DRYING TIME IS 60 HOURS.$ 7958. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.
IF DRYING TIME IS 72 HOURS.$ 9974. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.

IF DRYING TIME IS GREATER THAN 12.6 HOURS.IT WILL BE MORE ECONOMICAL TO ADD ADDITIONAL ICING INHIBITOR.
```

Figure 11b - Economic Analysis Showing Effect of Additional Additive Cost

# CHAPTER VII

## A PROPOSED FIELD TEST

The results obtained in the various tests conducted
in this thesis indicate that the method presented may someday
be operational. The author is aware that even now, after a
drying operation has been performed, some ships arrive at
their destination with jet fuel not meeting the icing inhibi-
tor specification. It is hoped that the information pre-
sented herein makes it clear that the additive is not lost
through any means other than water contact. The great major-
ity of vessels reach their destination with no additive loss,
and it may be expected that a vessel loaded in the manner
presented would experience no loss other than the loss
accounted for.

A method to load a vessel will now be presented which
the author considers feasible as an experiment to determine
if any problems not considered thus far will arise when the
thesis method is practically applied. The following assump-
tions will be made.

1. The gross quantity of barrels to be loaded aboard
   the vessel is known within 500 barrels. Let us assume
   138,300 gross barrels will be loaded.

2. It is assumed that the refinery has facilities to
   line blend the icing inhibitor into the fuel while
   loading, in any quantity desired.

3.  The average desired icing inhibitor content of the
    total cargo at equilibrium is 0.14 per cent.

4.  The fuel temperature is in the range of 70-80°F.
    By using Table 7, the average amount of additive
    which will be absorbed by water aboard the vessel
    is determined as 31 per cent.

The percentages used in Table 7 were selected from
the graph in Chapter III, page 21, and adjusted slightly
after running computer simulations to determine the most
desirable  value.

TABLE 7

ADDITIVE EQUILIBRIUM CONCENTRATIONS IN
FUEL AND SEA WATER

| Desired Additive Content in Fuel at Equilibrium | Additive Content in Water Bottoms at Equilibrium |
|---|---|
| Per Cent | Per Cent |
| 0.15 | 33.5 |
| 0.14 | 31.0 |
| 0.13 | 29.5 |
| 0.12 | 26.5 |
| 0.11 | 24.5 |
| 0.10 | 22.0 |

After the vessel arrives at the dock and has com-
pleted discharging ballast, a visual estimate of the water
remaining in each tank should be made.  Let us assume that a

total of 966 gallons are estimated to remain. This quantity when converted to barrels equals 23.0. The following calculations must be performed.

1.  Determination of additive quantity which will be absorbed by remaining ballast:

    0.31 X 23.0 = 7.13 barrels of additive

2.  Determination of additive quantity required for 0.14 per cent concentration after equilibrium:

    138,300 X 0.0014 = 193.6 barrels of additive

3.  Determination of additive percentage to be injected into fuel loaded aboard the vessel.

    $$\frac{(193.6 \div 7.13)100}{138,300} = \frac{20073}{138,300} = 0.145 \text{ per cent}$$

After loading is commenced, the shore loading line should be checked approximately every hour in order to determine that product containing 0.145 per cent additive is being loaded. The ship should be sampled frequently. It is possible that low additive concentrations will be experienced until a large quantity of fuel has been pumped aboard the vessel. After loading has been completed, average samples should be taken from each ship's tank and a composite sample should be made from these. The composite sample should test between 0.145 and 0.140 per cent additive. Until sufficient data has been accumulated to insure that the additive concentration is relatively uniform throughout the ship, each individual tank sample should be tested for additive concentration.

When the vessel arrives at the discharge port, the
water bottoms in each ship's tank could be pumped into the
receiving shore tank with the fuel and the water drained off,
or the water bottoms in each tank aboard the vessel could
be stripped into a shore slop tank prior to discharging
the fuel.

# CHAPTER VIII
## CONCLUSIONS AND RECOMMENDATIONS

1.  It would be economically desirable to use the proposed method since in most cases the additive concentration in the fuel loaded aboard the vessel need not contain any more icing inhibitor than is required by the military specification. In this case, assuming that the average tanker drying time is 12 hours and the average cost to operate a tanker is $168.00 per hour, an annual savings of over 4,000 hours in tanker turn-a-round would result in addition to a savings of approximately $700,000 in drying time. It is recommended, therefore, that field tests be conducted to determine if the method can be practically adopted.

2.  Even though the additive concentration in fuel at equilibrium is different in each ship's tank, it does not vary sufficiently to restrict any portion of the cargo from being discharged in a multiple port discharge situation.

3.  The additive equilibrium concentrations in known volumes of fuel and sea water may be predicted mathematically from available partitioning coefficients if the initial additive concentration in the fuel is known.

4.  A partitioning coefficient of 220 may be used to determine mathematically additive concentrations at equilibrium if

69

the fuel is in the 70-80°F temperature range. In order
to be as accurate as possible, the coefficient correspond-
ing to the temperature of the fuel should be used. This
coefficient may be determined from Figure 5, Chapter III.
Further study of actual additive concentrations in fuel
and sea water versus mathematical predictions at varying
temperatures would be desirable.

5.  The time required for equilibrium to be established aboard
a vessel must be determined by field test. Even though
the time required for equilibrium is not known, the
range in which the additive concentration should be upon
completion of loading is known. The additive concentra-
tion of the ship's composite sample after completion of
loading will indicate whether or not the additive concen-
tration at equilibrium will be within specification
limits.

6.  The small quantity of salt water remaining aboard the
vessel will not significantly affect the quality of
the fuel.

# REFERENCES

[1]W. C. French and E. A. Malick. Jet Fuel Anti-Icing Additives--A New Concept in Safety of Flight. Society of Automotive Engineers, Paper 356B, New York, 1961, p. 1.

[2]Defense Fuel Supply Center, Washington, D. C., phone conversation with Procurement Branch, December, 1967.

[3]Bureau of Naval Personnel. Fundamentals of Petroleum (Washington, D. C.: Bureau of Naval Personnel, 1965), p. 153.

[4]Letter from C. C. Dusek, Captain, U. S. N., Military Sea Transportation Service, Washington, D. C., Sept. 28, 1967.

[5]Bureau of Naval Personnel. op. cit., p. 143.

[6]Phillips Petroleum Company. PFA 55MB Fuel Additive (Bartlesville, Oklahoma: Phillips Petroleum Company, 1964), p. 5.

[7]Frank H. MacDougall. Physical Chemistry (New York: The Macmillan Company, 1949), p. 349.

[8]R. E. Linnard. Phillips Petroleum Company, Bartlesville, Oklahoma, personnal interview, November, 1967.

[9]Phillips Petroleum Company. op. cit., p. 6.

[10]R. E. Linnard. op. cit.

[11]Phillips Petroleum Company. op. cit., p. 19.

[12]Ibid., pp. 14-15.

[13]Defense Fuel Supply Center. Contract DSA-600-10692 (Washington, D. C.: Defense Fuel Supply Center, 1966), p. 6.

APPENDIXES

APPENDIX A

MILITARY SPECIFICATION TURBINE FUEL, AVIATION,

GRADES JP-4 and JP-5 (MIL-T-5624G)

MILITARY SPECIFICATION

TURBINE FUEL, AVIATION, GRADES JP-4 AND JP-5

This specification is mandatory for use by all Departments
and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope.- This specification covers two grades of aviation turbine
fuel (see 6.1).

1.2 Classification.- Aviation turbine fuel shall be of the following
grades, as specified (see 6.2):

| Grade | NATO No. | Description |
|-------|----------|-------------|
| JP-4 | F-40 | Wide-cut, gasoline type |
| JP-5 | F-44 | High flashpoint, kerosene type |

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for
bids or request for proposal, form a part of this specification to the extent
specified herein:

SPECIFICATIONS

Military

| | |
|---|---|
| MIL-I-25017 | Inhibitor, Corrosion, Fuel Soluble |
| MIL-I-27686 | Inhibitor, Fuel System Icing |

STANDARDS

Federal

| | |
|---|---|
| Federal Test Method Std. No. 791 | Lubricants, Liquid Fuels, and Related Products; Methods of Testing |

Military

| | |
|---|---|
| MIL-STD-290 | Packaging, Packing and Marking of Petroleum and Related Products |

FSC 9130

MIL-T-5624G

(Copies of specifications, standards, drawings, and publications required
by suppliers in connection with specific procurement functions should be
obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications.- The following documents form a part of this speci-
fication to the extent specified herein. Unless otherwise indicated, the issue
in effect on date of invitation for bids or request for proposal shall apply.

American Society for Testing and Materials Publications
   ASTM Standards Parts 17 and 18

(Copies of ASTM publications may be obtained from the American Society for
Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

3. REQUIREMENTS

3.1 Materials.- The fuel shall consist completely of hydrocarbon compounds,
except as otherwise specified herein.

3.2 Chemical and physical requirements.- The chemical and physical require-
ments of the finished fuel shall conform to those listed in table I. Require-
ments contained herein are not subject to corrections for test tolerances. If
multiple determinations are made, results falling within any specified repeat-
ability and reproducibility tolerances may be averaged.

3.2.1 Water reaction.- In addition to the interface rating specified in
table I, JP-4 fuel shall separate sharply from the water layer and there shall
be no evidence of an emulsion or precipitate, within or upon either layer.

3.3 Additives.- The additives listed herein may be used singly or in
combination in amounts not to exceed those specified. The type and amount of
each additive used shall be reported (see 6.3).

3.3.1 Antioxidants.- The following active inhibitors may be blended
separately or in combination into the fuel in total concentration not in excess
of 8.4 pounds of inhibitor (not including weight of solvent) per 1,000 barrels of
fuel (9.1 gm./100 gal. (U.S.), 24 mg./liter or 109 mg./gal.(U.K.)) in order to
prevent the formation of gum:

  (a) N,N' - diisopropyl-para-phenylenediamine
  (b) N,N' - disecondary butyl-para-phenylenediamine
  (c) 2,6-ditertiary butyl-4-methylphenol
  (d) 2,4-dimethyl-6-tertiary butylphenol
  (e) 2,6-ditertiary butylphenol
  (f) 75 percent min. 2,6-ditertiary butylphenol
    25 percent max. tertiary and tritertiary butylphenols

MIL-T-5624G

TABLE I. Chemical and physical requirements and test methods

| Requirements | Fuel | | Test method | |
| --- | --- | --- | --- | --- |
| | Grade JP-4 NATO No. F-40 | Grade JP-5 NATO No. F-44 | Fed. Test Method Std. No. 791 | ASTM standards |
| Distillation: | | | | |
|   Initial boiling point | 1/ | 1/ | | |
|   Fuel evaporated, 10 percent min. at | 1/ | 400° F (204.4° C) | 1001 | D86 2/ |
|   Fuel evaporated, 20 percent min. at | 290° F (143.3° C) | 1/ | | |
|   Fuel evaporated, 50 percent min. at | 370° F (187.8° C) | 1/ | | |
|   Fuel evaporated, 90 percent min. at | 470° F (243.3° C) | | | |
|   End point, max. | 1/ | 550° F (287.8° C) | | |
|   Percent evaporated, at 400° F (204.4° C) | 1/ | | | |
|   Residue, vol. percent max. | 1-1/2 | 1-1/2 | | |
|   Distillation loss, vol. percent max. | 1-1/2 | 1-1/2 | | |
| Gravity °API - min. (sp. gr. max.) | 45.0 (0.802) | 36.0 (0.845) | 401 | D287 |
| Gravity °API - max. (sp. gr. min.) | 57.0 (0.751) | 48.0 (0.788) | 401 | D287 |
| Existent gum, mg./100 ml. max. | 7 | 7 | 3302 | D381 |
| Total potential residue, 16 hour aging, mg./100 ml. max. | 14 | 14 | 3354 | D873 |
| Sulfur, total, percent weight max. | 0.4 | 0.4 | 5201 | D1266 |
| Mercaptan sulfur, percent weight max. 3/ | 0.001 | 0.001 | 5204 | D1219 or D1323 |
| Reid vapor pressure, 100° F, psi, min., (gm./cm.2, min.) | 2.0 (140.6) | ---- | 1201 | D323 |
| Reid vapor pressure, 100° F, psi, max., (gm./cm.2, max.) | 3.0 (210.9) | ---- | 1201 | D323 |
| Freezing point, max. | -72° F (-58° C) | -51° F (-46° C) | 1411 | D2386 |
| Heating value: | | | | |
|   Net heat of combustion, Btu/lb., min., or aniline-gravity product, min. 4/ | 18,400 5,250 | 18,300 4,500 | 2502 3601 and 401 | D240 D611 and D287 |
| Viscosity, centistokes at -30° F (-34.4° C); max. | ---- | 16.5 | 305 | D445 |
| Aromatics, vol. percent max. | 25.0 | 25.0 | 3703 | D1319 |
| Olefin, vol. percent max. | 5.0 | 5.0 | 3703 | D1319 |

See footnotes at end of table

MIL-T-5624G

TABLE I. Chemical and physical requirements and test methods (continued)

| Requirements | Fuel | | Test method | |
| --- | --- | --- | --- | --- |
| | Grade JP-4 NATO No. F-40 | Grade JP-5 NATO No. F-44 | Fed. Test Method Std. No. 791 | ASTM standards |
| Smoke point, mm. min. | ---- | 19.0 | 2107 | D1322 |
| or luminometer No., min. | ---- | 50 | 2108 | D1740 |
| Explosiveness, percent max. | ---- | 50 | 1151 | ---- |
| Flash point, min. | ---- | 140° F (60.0° C) | 1102 | D93 |
| Smoke volatility index, min. | 52.0 5/ | ---- | | |
| or luminometer No., min. | 60 | ---- | 2108 | D1740 |
| Copper strip corrosion, ASTM classification max. | No. 1 | No. 1 | 5325 | D130 6/ |
| Water separometer index, min. | 85 | 85 | 3256 | ---- |
| Water reaction, interface rating, max. | 1b. | ---- | 3251 | ---- |
| Thermal stability: | | | | |
| Change in pressure drop in 5 hours, in. of Hg, max. | 3 | 3 | 3464 7/ | D1660 7/ |
| Preheater deposit less than | 3 | 3 | ---- | ---- |
| Particulate matter, | | | | |
| mg./gal. max. F.O.B. origin deliveries | 4 | ---- | 3008 | D2276 |
| mg./gal. max. F.O.B. destination deliveries | 8 | ---- | 3008 | D2276 |
| Fuel system icing inhibitor, percent vol., max. | 0.15 | ---- | 5327 or 5340 | ---- |
| Fuel system icing inhibitor, percent vol., min. | 0.10 | ---- | 5327 or 5340 | ---- |

1/ To be reported-not limited.
2/ A condenser temperature of 32° to 40° F shall be used for the distillation of grade JP-5. For JP-4, use group 3 test conditions.
3/ The mercaptan sulfur determination may be waived at the option of the inspector if the fuel is "doctor sweet" when tested in accordance with Method 5203 of Federal Test Method Standard No. 791.
4/ Aniline-gravity product is defined as the product of the gravity in °API and the aniline point in ° F.
5/ The smoke volatility index (SVI) is the smoke point (SP) + (0.42 X volume percent boiling under 400° F (204.4° C)).
6/ To be performed in accordance with paragraph titled, "Tests at 212° F (100° C) volatile materials" of ASTM D130-56.
7/ See (4.6.1) for test conditions.

MIL-T-5624G

3.3.2 Metal deactivator.- A metal deactivator, N, N'-disalicylidene-1, 2 propane-diamine may be blended into the fuel in an amount not to exceed 2 pounds of active ingredient per 1,000 barrels of fuel (2.2 gm./100 gal. (U.S.), 5.8 mg./liter or 25 mg./gal. (U.K.)).

3.3.3 Corrosion inhibitor.- A corrosion inhibitor shall not be added to grade JP-4 or JP-5 fuel by the supplier or the transporting agency unless prior approval is obtained from the procuring agency. When used, the corrosion inhibitor shall conform to MIL-I-25017 and the finished fuel shall meet all the requirements specified in section 3. No limit is placed on the minimum amount which may be added. The maximum allowable concentration shall not exceed that listed in the latest revision of QPL-25017. If a corrosion inhibitor is used, the contractor or transporting activity, or both, shall maintain and upon request, make available to the Government, evidence that the corrosion inhibitors used are equal in every respect to the product specified in MIL-I-25017.

3.3.4 Fuel system icing inhibitor.- The fuel system icing inhibitor shall conform to MIL-I-27686.

3.4 Workmanship.- The finished fuel shall be visually free from un-dissolved water, sediment or suspended matter and shall be clean and bright at the ambient temperature or at 70° F, whichever is higher.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection.- Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of tests.- For acceptance purposes, individual lots shall be subjected to all tests and other requirements cited in section 3.

4.3 Inspection lot.-

4.3.1 Bulk lot.- An indefinite quantity of a homogeneous mixture of material offered for acceptance in a single isolated container.

4.3.2 Packaged lot. - An indefinite number of 55-gallon drums or smaller unit packages of identical size and shape offered for acceptance and filled from one isolated tank containing a homogeneous mixture of material.

4.4 Sampling.- Each bulk or packaged lot of material shall be sampled for verification of product quality and compliance with MIL-STD-290 as applicable, in accordance with Method 8001 of Federal Test Method Standard No. 791 (ASTM D270).

MIL-T-5624G

4.5 Inspection.- Inspection shall be in accordance with Method 9601 of Federal Test Method Standard No. 791.

4.6 Test methods.- Tests, to determine conformance to chemical and physical requirements, shall be conducted in accordance with Federal Test Method Standard No. 791 or ASTM standards, using the applicable methods as listed in table I, except for the following.

4.6.1 Thermal stability.- The thermal stability test shall be conducted using a preheater temperature of 300° F, a filter temperature of 400° F, a fuel flow of 6 pounds per hour over a test period of 300 minutes.

4.6.1.1 Reported data.- The following data shall be reported:

(a) Differential pressure in inches of mercury at 300 minutes, or time to a differential pressure of 3 inches of mercury, whichever comes first.
(b) Preheater deposit code rating at the end of the test.

5. PREPARATION FOR DELIVERY

5.1 Packaging, packing, and marking.- Packaging, packing and marking shall be in accordance with MIL-STD-290.

6. NOTES

6.1 Intended use.- The fuel covered by this specification is intended for use in aircraft turbine engines, ramjet engines, and rocket engines.

6.2 Ordering data.- Procurement documents should specify:

(a) Title, number, and date of this specification.
(b) Grade of fuel required (see 1.2).
(c) Quantity required and size containers desired.
(d) Level of packaging and packing required (see 5.1).

6.3 Precaution for mixing inhibitors.- To prevent any possible reaction between the concentrated forms of different inhibitors (see 3.3), the fuel supplier is cautioned not to commingle inhibitors prior to their addition to the fuels.

6.4 International agreements.- Certain provisions of this specification are the subject of international standardization agreement (ASCC 15/1- STANAG No. 1135). When amendment, revision, or cancellation of this specification is proposed, the departmental custodians will inform their respective Departmental Standardization Offices so that appropriate action may be taken respecting the international agreement concerned.

MIL-T-5624G

Custodians:
  Army - MR
  Navy - WP
  Air Force - (11)

Reviewer activities:
  Army - MR
  Navy - WP
  Air Force - (11), (68)

User activities:
  Army - MI, MO
  Navy -
  Air Force -

International interest (see 6.4)

Preparing activity:
  Air Force - (11)

Project No. 9130-0017

APPENDIX B

MILITARY SPECIFICATION, INHIBITOR, FUEL SYSTEM ICING

(MIL-I-27686D and Amendment 1)

# MILITARY SPECIFICATION

# INHIBITOR, FUEL SYSTEM ICING

*This specification has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy, and the Air Force.*

## 1. SCOPE

**1.1** This specification covers one type and grade of inhibitor, anti-icing, soluble in jet turbine fuels.

## 2. APPLICABLE DOCUMENTS

**2.1** The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

STANDARDS

FEDERAL

Fed. Test Method Std. No. 141—Paint, Varnish, Lacquer, and Related Materials; Methods of Inspection, Sampling, and Testing.

Fed. Test Method Std. No. 791—Lubricants, Liquid Fuels, and Related Products; Methods of Testing.

MILITARY

MIL-STD-105—Sampling Procedures and Tables for Inspection by Attributes.

MIL-STD-290—Packaging, Packing and Marking of Petroleum and Related Products.

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

**2.2** Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply:

AMERICAN SOCIETY FOR TESTING AND MATERIALS PUBLICATIONS

E70-52T—Determination of pH of Aqueous Solutions with the Glass Electrode.

D891—Tests for Specific Gravity of Industrial Aromatic Hydrocarbons and Related Materials.

D1078—Test for Distillation Range of Lacquer Solvents and Diluents.

D1209—Test of Color of Clear Liquids.

D1218—Measurement of Refractive Index and Refractive Dispersion of Hydrocarbon Liquids.

D1364—Test for Water in Lacquer Solvents and Diluents.

D1613-61T—Test for Acidity in Lacquer Solvents and Diluents.

(Copies of ASTM publications may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa., 19103.)

## 3. REQUIREMENTS

**3.1** Materials. The ingredient materials used in the manufacture of the inhibitor shall conform to the requirements specified herein.

**3.1.1** *Certification.* The manufacturer shall certify that the ingredient materials have been included in the proportions specified in 3.2.

**3.2** Composition. The composition of the inhibitor shall be as specified in table I.

TABLE I. *Composition*

| Ingredient material | Percent (by weight) |
|---|---|
| Ethylene glycol monomethyl ether | 99. 6 ± 0. 04 |
| Glycerol | 0. 4 ± 0. 04 |

FSC 6850

## MIL-I-27686D

**3.2.1** *Properties.* The ethylene glycol mono-methyl ether ingredient shall have the properties specified in table II.

**3.2.2** *Glycerol.* The glycerol ingredient shall have the properties specified in table III.

**3.3** Properties of the compounded inhibitor. The compounded inhibitor shall conform to the requirements specified in table IV.

TABLE II. *Properties of ethylene glycol monomethyl ether ingredient*

| Property | Requirement |
|---|---|
| Acid number, mg. KOH per gram (maximum). | 0.09 |
| Color, platinum cobalt (maximum)_ | 15 |
| Distillation: | |
|     Initial point (minimum)_____ | 123.5° C |
|     Dry point (maximum)_____ | 125.5° C |
| Ethylene glycol (maximum)_____ | 0.025 weight percent |
| Specific gravity (20°/20° C)_____ | 0.963 to 0.967 |

TABLE III. *Properties of glycerol ingredient*

| Property | Requirement |
|---|---|
| Acid number, mg. KOH per gram (maximum). | 0.09 |
| Color, platinum cobalt (maximum)_ | 20 |
| pH of 25% solution in water (25° ±2° C). | 6.0 to 7.0 |
| Specific gravity (20°/20° C)_____ | 1.2623 to 1.2636 |
| Water, percent by weight (maximum). | 0.5 |

TABLE IV. *Properties of the compounded inhibitor*

| Property | Requirement |
|---|---|
| Acid number, mg. KOH per gram (maximum). | 0.09 |
| Color, platinum cobalt (maximum)_ | 20 |
| Glycerol_____ | 0.36 to 0.44 weight percent |
| pH of 25% solution in water (25° ±2° C). | 6.0 to 7.0 |
| Refractive index (25° C)_____ | 1.4000 to 1.4010 |
| Specific gravity (20°/20° C)_____ | 0.965 to 0.969 |
| Water (maximum)_____ | 0.2 weight percent |

**3.4** Workmanship. The ingredient materials shall be assembled and processed in accordance with high-grade commercial practice to produce an inhibitor uniform in quality and free from suspended and foreign matter (see 4.5.1).

## 4. QUALITY ASSURANCE PROVISIONS

**4.1** Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any other commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

**4.2** General inspection provisions. Except where otherwise indicated, the provisions of this section are applicable to the compounded inhibitor. The quality assurance of ingredient materials covered by applicable specifications shall be in accordance with such specifications. Sampling and inspection of ingredient materials not covered by separate specifications shall be as specified herein. Unless otherwise specified, general inspection provisions shall be in accordance with Method 9601 of Federal Test Method Standard No. 791.

**4.3** Sampling.

**4.3.1** *Sampling of ingredient materials.* The ethylene glycol monomethyl ether and glycerol ingredient materials shall be sampled in accordance with Method 8001 of Federal Test Method Standard No. 791. Samples selected for ethylene glycol monomethyl ether shall be subjected to the tests for acid number, color, distillation, ethylene glycol (percent), and specific gravity as specified in 4.6.1 through 4.6.1.1.3. Samples selected for glycerol shall be subjected to the tests for acid number, color, specific gravity, water, glycerol (percent by weight) and pH of 25 percent solution in water as specified in 4.6.1, 4.6.1.2, and 4.6.1.3. Sampling and testing of the ingredient materials shall be conducted prior to compounding.

**4.3.2** *Sampling of product.* The inhibitor shall be sampled in accordance with Method 8001 of Federal Test Method Standard No. 791. The samples shall be subjected to the examination of product and all tests specified under 4.6, with the exception of the test for

ethylene glycol (percent by weight) (see 4.6.1.1).

**4.3.3** *Sampling for inspection of filled containers.* A random sample of filled containers shall be selected from each lot, in accordance with Standard MIL-STD–105, inspection level I, AQL of 2.5 percent defective. The sample containers shall be subjected to the examination of filled containers as specified in 4.5.2.

**4.4** Report of tests. The manufacturer shall submit test reports to the procuring activity showing the results of all tests specified herein. The report shall be accompanied by the certification of ingredients as required in 3.1.1.

**4.5** Examinations.

**4.5.1** *Examination of product.* Samples selected in accordance with 4.3.2 shall be visually examined for compliance with 3.4.

**4.5.2** *Examination of filled containers.* Each container selected as specified in 4.3.3 shall be examined for defects of the container and closure, for evidence of leakage, for unsatisfactory markings and all other preparation for delivery requirements. Each filled container shall also be weighed to determine the amount of contents. Any container in the sample having one or more defects or under required fill shall be rejected.

**4.5.3** *Examination of empty containers.* Containers shall not contain any foreign material, such as solids, corrosion products, water, or other sediments. Container seams shall be inspected for evidence of metal erosion, flux, solder, and such materials as would contaminate the product. Any container not meeting these criteria shall be rejected.

**4.6** Test methods.

**4.6.1** The inhibitor and its ingredient materials shall be tested in accordance with test methods listed in table V and other methods as described in 4.6.1.1, 4.6.1.2, and 4.6.1.3.

**4.6.1.1** *Ethylene glycol (percent by weight).* The percent of ethylene glycol in the ethylene glycol monomethyl ether component shall be determined as specified in the following subparagraphs.

**4.6.1.1.1** *Reagents and materials.* Unless otherwise indicated, all reagents shall be American Chemical Society reagent grade, or equivalent. References to water indicate dis-

TABLE V. *Test methods*

| Test | ASTM Method No. |
|---|---|
| Acid number | D1613–61T |
| Color | D1209 |
| Distillation | D1078 |
| Refractive index | D1218 |
| Specific gravity | D891 (Method C) |
| Water | D1364 |

tilled or deionized water. The following materials shall be prepared:

  (a) Oxidizing reagents: To a solution of 5 grams (g.) of periodic acid ($HIO_4$) in 200 milliliters (ml.) of water, add 800 ml. of glacial acetic acid. Store the solution in a dark, well-stoppered bottle.

  (b) Potassium iodide: Twenty percent aqueous solution.

  (c) Sodium thiosulfate, standard 0.1 N: Standardize by an accepted procedure.

  (d) Starch indicator solution: One percent aqueous.

**4.6.1.1.2** *Procedure.* The following procedure shall be performed:

  (a) Pipette 50 ml. of the oxidizing reagent into each of four 500-ml. iodine flasks. Reserve two of the flasks for the blank determination.

  (b) Introduce 50 g. of the sample, weighed to the nearest 0.1 g., into each of two flasks and swirl to effect solution.

  (c) Allow the flasks to stand for 30 minutes at room temperature.

  (d) While swirling, add 10 ml. of 20-percent potassium iodide solution to each flask in turn immediately before titrating.

  (e) Titrate the contents of each flask to a pale yellow color with standard 0.1 N sodium thiosulfate. Add 1 ml. of starch indicator and titrate to the disappearance of the blue color.

  (f) If the net titration is more than 20 ml., repeat the determination, using a smaller sample size.

**4.6.1.1.3** *Calculations.* Calculate the concentration of ethylene glycol as:

Weight percent ethylene glycol

$$= \frac{(B-A)\,(N)\,(3.103)}{(S)}$$

MIL-I-27686D

Where A=ml. of sodium thiosulfate required for the sample

B=average ml. of sodium thiosulfate required for the blank

N=normality of sodium thiosulfate

S=grams of sample.

**4.6.1.2** *Glycerol (percent by weight).* The procedure shall be as specified in 4.6.1.1.2, except the sample size shall weigh 10 g. to the nearest 0.1 milligram.

**4.6.1.2.1** *Calculations.* Calculate the concentration of glycerol as:

$$\text{Weight percent glycerol} = \frac{(B-A)(N)(2.302)}{S}$$

Where A=ml. of sodium thiosulfate required for the sample

B=average ml. of sodium thiosulfate required for the blank

N=normality of sodium thiosulfate

S=weight of sample (gram).

**4.6.1.3** *pH of 25 percent solution in water.* Twenty-five ml. of the inhibitor shall be pipetted into a 100-ml. volumetric flask and filled with freshly boiled and cooled distilled water having a pH of 6.5 to 7.5. The pH value shall be measured with a pH meter calibrated in accordance with ASTM Method E70-52T.

## 5. PREPARATION FOR DELIVERY

**5.1** Packaging, packing, and marking. The packaging, packing, and marking shall be in accordance with Standard MIL-STD-290. The shipment marking nomenclature shall be: INHIBITOR, FUEL SYSTEM ICING.

**5.1.1** *Precautionary markings.* In addition to the markings required by 5.1, each container shall be marked with the following precautionary marking:

TO BE USED ONLY AS AN ANTI-ICING ADDITIVE FOR JET TURBINE ENGINE FUELS.

## 6. NOTES

**6.1** Intended use. The inhibitor is intended for use as an anti-icing agent to be added to jet turbine engine fuels.

**6.2** Ordering data. Procurement documents should specify:

(a) Title, number, and date of this specification.

(b) Responsibility for inspection records, if other than supplier (see 4.1).

(c) Applicable levels of packaging and packing (see 5.1).

**6.2.1** *Unit of purchase.* Unit of purchase is the U.S. gallon of 231 cubic inches at 15.5° C (60° F).

**6.3** International standardization. Certain provisions of this specification are the subject of international standardization agreement ABC AIR STD 15/1 and STANAG 3437. When amendment, revision, or cancellation of this specification is proposed, the departmental custodians will inform their respective Departmental Standardization Offices so that appropriate action may be taken respecting the international agreement concerned.

**6.4** Marginal indicia. The margins of this specification are marked to indicate where changes, deletions, or additions to the previous issue have been made. This is done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Figures are not so marked. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content as written, irrespective of the marginal notations and relationship to the last previous issue.

Custodians:
Army—MU
Navy—Weps
Air Force—ASD (11)
International interest (see 6.3)
Reviewer activity:
Army—
Navy—Weps
Air Force—ASD (11)
User activity:
Army—
Navy—
Air Force—
Preparing activity:
Air Force—ASD (11)
Project No. 6850-0132

Review/user information is current as of the date of this document. For future coordination of changes to this document, draft circulation should be based on the information in the current Federal Supply Classification Listing of DoD Standardization Documents.

MILITARY SPECIFICATION

INHIBITOR, FUEL SYSTEM ICING

This amendment forms a part of Military Specification MIL-I-27686D, 17 September 1964, and is mandatory for use by all Departments and Agencies of the Department of Defense.

Page 1:  Add as new paragraph:

"1.2  Classification. - The NATO symbol for this material is as follows:

S-748  "

Page 2, table II:  Add the following as last two items of table:

| Property | Requirement |
|---|---|
| "pH of 25% solution in water (25° +2° C) | 6.0 to 7.0 |
| Water, percent by weight (maximum) | 0.15". |

Page 4, paragraph 6.3, fourth line:  Delete "STANAG 3437" and substitute "STANAG 1135"

Custodians:
   Army - MU
   Navy - AS
   Air Force - (11)

Reviewer activities:
   Army - MU
   Navy - AS
   Air Force - (11), (68)

Preparing activity:
   Air Force - (11)

Project No. 6850-0288

FSC 6850

# APPENDIX C
## DETERMINATION OF FUEL SYSTEM ICING
## INHIBITOR IN HYDROCARBON FUELS
### (Federal Test Method 5340)

# DETERMINATION OF FUEL SYSTEM ICING INHIBITOR IN HYDROCARBON FUELS
## (Refractometer Method)

## 1. SCOPE

**1.1** This method is used for the determination of 0.05 to 0.20 volume percent ethylene glycol monomethyl ether, $CH_3O(CH_2)_2OH$, and glycerine, $CHOH (CH_2OH)_2$ as icing inhibitor in turbine fuels. Refer to Mil. Spec. MIL–I–27686 for details on fuel system icing inhibitor. The test consists of removing the ethylene glycol monomethyl ether and glycerin from the hydrocarbon fuel by extraction with water. The amount of icing inhibitor in the extract is determined by measuring the difference between its refractive index and that of the water used in making the extraction.

## 2. SPECIMEN

**2.1** Eight hundred ml. of hydrocarbon fuel.

## 3. APPARATUS

**3.1 Portable differential refractometer kit.** The kit includes the differential refractometer and all other equipment necessary to perform the evaluation. All items except the differential refractometer are standard laboratory items available from supply house.

Note 1. The kit used in this test method is available from the Seiscor Products Section, Seismograph Service Corp., P.O. Box 1590, Tulsa, Oklahoma. It contains, in addition to the refractometer, a built in ring stand, a one-liter separatory funnel, a 200 ml. graduate, syringe and needle for cell cleaning, one polyethylene wash bottle, one polyethylene bottle for distilled water, one glass bottle, four glass vials, and a tube of stopcock grease. All the above are housed in a luggage type case.

## 4. MATERIALS

**4.1 Ethylene glycol monomethyl ether-glycerin standard solution for calibration of instrument.** (These solutions should be made in a laboratory where necessary equipment is available). Pipet 8.0 ml. of ethylene glycol monomethyl ether-glycerin solution into 500.0 ml. of distilled water (volumes must be accurate) and mix thoroughly. The final solution is equivalent to 0.10 volume percent of ethylene glycol monomethyl ether-glycerin in fuel. Repeat using 4.0, 12.0, and 16.0 ml. of ethylene glycol monomethyl ether-glycerin solution in the first step thereby making standard solutions of equivalent 0.05, 0.15, and 0.20 volume percent in fuel.

**4.2** Distilled water.

**4.3** Weak water-detergent solution consisting of 1 quart commercial liquid dishwashing detergent to 100 parts distilled water.

## 5. PROCEDURE

**5.1** Preliminary steps in zeroing instrument. With light switch released, zero potentiometer with the screw located directly below the scale. Fill all the cells of the cell block with distilled water. Place cell block in light path and close cover. Zero the meter with the adjusting screw located near the upper right corner of the potentiometer. Clean and dry center cell of cell block. (Use weak detergent, rinse with distilled water, and dry with syringe and needle provided).

**5.2 Calibration curve.** This is prepared by determining differential refractive index measurements on the known solutions listed in 4.1, and plotting the vernier reading against the known amount of icing inhibitor. Once a curve has been prepared for a given-

cell and instrument, it can be used indefinitely. (If batteries are changed, or minor repairs made, checking of one point on the calibration curve should be sufficient. If the cell block is replaced, a new calibration curve should be drawn).

**5.3 Extraction of hydrocarbon fuel.** Measure 800 ml. of hydrocarbon fuel to be tested, into a one-liter separatory funnel. Measure 50 ml. of distilled water into the fuel in the one-liter separatory funnel. Shake the separatory funnel vigorously by hand for three minutes. Place the funnel in a ring holder so that the layers may separate. Then draw off most of the water layer into a previously cleaned and dried two-ounce bottle. TAKE CARE NOT TO DRAW OFF ANY OF THE HYDROCARBON LAYER.

**5.4 Differential refractive index measurement.** Using the syringe and special needle supplied, rinse the center cell three times with the extract. Place cell block in the refractometer. Depress the light switch located near the left front corner of the instrument. Zero the potentiometer by rotating the vernier scale. Note reading on vernier scale and apply to calibration curve to obtain volume percent anti-icing additive in the sample of fuel.

## 6. PRECISION

**6.1** Duplicate determinations should not differ from the mean by more than $\pm$ 0.005 in the range of 0.05 to 0.20 volume percent ethylene glycol monomethyl ether-glycerin.

Preparing activity.

**Air Force—WPAFB, 1964**

APPENDIX D

DETERMINATION OF FUEL SYSTEM ICING

INHIBITOR IN HYDROCARBON FUELS

(Federal Test Method 5327.3)

# DETERMINATION OF FUEL SYSTEM ICING INHIBITOR IN HYDROCARBON FUELS

## 1. SCOPE

**1.1** This method is used for determination of 0.05 to 0.20 volume percent ethylene glycol monomethyl ether $CH_3O(CH_2)_2OH$ and glycerol $CHOH(CH_2OH)_2$ (synonym: methyl cellosolve and glycerin in hydrocarbon fuels). The test consists of removing the methyl cellosolve and glycerin from the hydrocarbon fuel by extraction with water. The water solution is allowed to react with an excess of standard potassium dichromate solution in the presence of sulfuric acid, and the excess dichromate is determined idometrically.

## 2. SPECIMEN

**2.1** 25.0 ml. of hydrocarbon fuel.

## 3. APPARATUS

**3.1** Erlenmeyer flask. 50 ml.

**3.2** Hotplate.

**3.3** Iodine flask. 500 ml.

**3.4 Separatory funnels.** One hundred twenty five ml., pear shaped with supportings and stand.

**3.5 Test tubes.** Pyrex 22 x 175 mm., with support rack.

**3.6 Volumetric glassware.**

**3.6.1** Burets, 25, 50 ml.

**3.6.2** Pipets, 5, 10, 25 ml.

**3.6.3** Flasks, 100, 500, 1000 ml.

**3.7** Glass stoppered bottles.

**3.8** Interval timer.

## 4. REAGENTS AND MATERIALS

Unless otherwise indicated, all reagents shall conform to the specification established by the Committee on Analytical Reagents of the American Chemical Society where such specifications are available. References to water shall be understood to mean distilled or deionized water.

**4.1** Crushed ice.

**4.2 Methyl cellosolve-glycerine standard solution.** Pipet 10.00 ml. of methyl cellosolve-glycerin solution into a 1-liter volumetric flask. Dilute to volume with water and mix thoroughly. Pipet 10.00 ml. of the diluted additive into 100-ml. volumetric flask, dilute to volume with water and mix thoroughly. The final solution contains 0.10 percent by volume of methyl cellosolve-glycerin.

**4.3 Potassium dichromate solution, standard** 0.2000 $N$. Dissolve exactly 4.9035 g. of potassium dichromate (dried 1 hour at 110°C.) in water. Transfer to a 500-ml. volumetric flask and dilute with water to volume. Mix thoroughly.

**4.4 Potassium iodide.** Crystals.

**4.5 Sodium thiosulfate solution, standard** 0.100 $N$. Dissolve 25 $\pm$ 0.1 g. of sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$) in 1 liter of water. Add 0.01 g. of sodium carbonate to stabilize the solution and mix thoroughly. Allow the solution to stand 24 hours before standardizing. This solution should be standardized every two weeks. To standardize, pipet 10.00 ml. of 0.2000 $N$ potassium dichromate into a 500 ml. iodine flask, add 5.00 ml. of concentrated sulfuric acid slowly from a buret. Add about 50 ml. of water and cool to room temperature. Add approximately 3 g. of potassium iodide and mix thoroughly. Titrate with the sodium thiosulfate solution, swirling the liquid constantly until a brown color has changed to a yellowish green. Add 2 ml. of starch indicator solution and continue the titration until the color changes sharply from dark blue to a light bluish-green. When ap-

**FED. TEST METHOD STD. NO. 791a**

proaching the end point be careful to swirl the iodine flask and contents vigorously after the addition of each drop of thiosulfate. Calculate the normality of the sodium thiosulfate solution as follows:

$$\text{Normality } (N) \text{ of } Na_2S_2O_3 = \frac{(\text{ml. } K_2Cr_2O_7) \quad (NK_2Cr_2O_7)}{Ml. \ Na_2S_2O_3}$$

4.6 Starch indicator solution. Mix 4 grams of soluble starch and 10 mg. of mercuric iodide (preservative with 10 ml. of water, and add the suspension slowly to 1 liter of boiling water). Boil for 5 minutes. Cool the solution and store in a glass stoppered bottle.

4.7 Sulfuric acid. Concentrated, sp. gr. 1.84.

## 5. PROCEDURE

5.1 Determination of factor F. Definition: factor $F = $ ml. of methyl cellosolve-glycerin per milli-equivalent of potassium dichromate. Pipet 5.00 ml. of the methyl cellosolve-glycerin standard solution (4.2) into a 22 x 175 mm. test tube. Add from a pipet 10.0 ml. of 0.2000 $N$ potassium dichromate solution and place the test tube in an ice bath. After the solution has been chilled add from a buret 5.00 ml. of concentrated sulfuric acid while constantly swirling the test tube in the ice bath. THOROUGH MIXING OF THE ACID AND AQUEOUS PHASES WITHOUT OVERHEATING IS IMPERATIVE. After the solution has cooled, place the test tube in a bath of boiling water for exactly 10 minutes. Return the test tube to the ice bath and allow to cool to room temperature or below. Transfer the contents of the test tube to a 500-ml. iodine flask. Wash the test tube 4 times with 5-ml. portions of water and add the washings to the iodine flask. Add approximately 3 g. of potassium

iodide and titrate with the standard 0.1 $N$ sodium thiosulfate solution to a starch end point. The starch end point is described in 4.5. When approaching the end point be careful to swirl the iodine flask vigorously after the addition of each drop of thiosulfate.

Make three determinations of factor $F$ and calculate the average value. None of the three should differ from the average by more than $\pm 0.0001$.

$$F = \frac{0.005}{(V_D N_D) - (V_T N_T)} = \frac{0.005}{2.00 - (V_T N_T)}$$

where:

0.005 = ml. of methyl cellosolve-glycerin in aliquot of standard solution analyzed.

$V_D$ = ml. potassium dichromate.

$N_D$ = normality of potassium dichromate.

$V_T$ = ml. sodium thiosulfate.

$N_T$ = normality of sodium thiosulfate.

5.2 Analysis of hydrocarbon fuel. Pipet 25.0 ml. of sample into a dry 125-ml. separatory funnel, and add from a pipet 25.0 ml. of water. Stopper the funnel and shake vigorously for 2 minutes. Allow the two phases to separate, and drain the water layer into a dry 50-ml. Erlenmeyer flask. Pipet 5.00 ml. of this solution into a 22 x 175 mm. test tube. Add from a buret or pipet 10.00 ml. of 0.2000 $N$ potassium dichromate solution, and place the test tube in an ice bath. After the solution has been chilled add from a buret 5.00 ml. of concentrated sulfuric acid while constantly swirling the test tube in the ice bath. THOROUGH MIXING OF THE ACID AND AQUEOUS PHASES WITHOUT OVERHEATING IS IMPERATIVE. After the solution has cooled, place the test tube in a bath of boiling water for exactly 10 minutes. Cool the solution to room temperature in an ice bath. Quantitatively transfer the solution to a 500 ml. iodine flask, rinsing the

test tube four times with 5 ml. portions of water and adding the washings to the flask. Add approximately 3 g. of potassium iodide, and titrate with standard 0.1 $N$ sodium thiosulfate solution to a starch end point. The starch end point is described in 4.5. When approaching the end point be careful to swirl the iodine flask vigorously after the addition of each drop of the thiosulfate. THE METHOD IS NOT APPLICABLE IF THE VOLUME OF THIOSULFATE USED IN THE TITRATION IS LESS THAN 5.0 ML.

5.3 Make a blank determination by repeating the above procedure using a sample of the fuel (under test) taken before the introduction of the additive.

## 6. CALCULATIONS

6.1 Calculate the methyl cellosolve-glycerin content of the hydrocarbon fuel as follows:

Volume % methyl cellosolve-glycerin =

$$\frac{100\ F \left[ (V_D N_D) - (V_T N_T) \right]}{AS}$$

where:

$F$ = factor defined in par. 5.1

$V_D$ = ml. of potassium dichromate.

$N_D$ = normality potassium dichromate.

$V_T$ = ml. of sodium thiosulfate.

$N_T$ = normality sodium thiosulfate.

$A$ = aliquot fraction of water extract used.

$S$ = ml. of hydrocarbon fuel sample.

When the instructions in this method are followed exactly, the equation may be reduced to:

Volume % methyl cellosolve-glycerine =

$$20F \left[ 2.000 - (V_T N_T) \right]$$

6.2 Calculate the value of the blank in the same manner as for the sample.

6.3 Subtract the blank value from that obtained in 6.1 to obtain the corrected volume percent of methyl cellosolve-glycerin for report. If normally high FS11 values are obtained on the finished blend at the point of receipt, it is recommended that the local Quality Control office be requested to obtain a sample of the uninhibited fuel from the source of supply to use in making blank determinations on this product.

## 7. PRECISION

Duplicate determinations should not differ from the mean by more than $\pm$ 0.005 in the range of 0.05 to 0.20 volume percent methyl cellosolve-glycerin.

Preparing activity:

Air Force—WPAFB, 1961

APPENDIX E

THE COMPUTER PROGRAM

# THE COMPUTER PROGRAM

## Input Variables Defined

DESAIA - the desired anti-icing content of the total cargo at
equilibrium.  Limited to the following values 0.10,
0.11, 0.12, 0.13, 0.14, 0.15.

NUMWTK - the number of wing tanks the vessel has per side.

NUMCTK - the number of center tanks in the vessel.

PRICE - the additional cost per gallon of JP4 if the additive
treatment exceeds the maximum specification limit of
0.15 per cent by volume.  The additional cost is read
in dollars per gallon of product.

DRYCST - the cost per hour to operate the tanker, i.e. the
dollars lost per hour while the vessel is drying
tanks at the pier.

H2OEST - the total barrels of water estimated aboard the tanker.
If value is zero, the additive concentration in the
fuel pumped to the ship is calculated, using the
actual water aboard the vessel.

FUELS(I) - the product quantity in barrels to be loaded into
each starboard tank.

FUELC(I) - the product quantity in barrels to be loaded into
each center tank.

FUELP(I) - the product quantity in barrels to be loaded into
each port tank.

95

WATERS(I) - the water quantity in barrels remaining in each
starboard tank.

WATERC(I) - the water quantity in barrels remaining in each
center tank.

WATERP(I) - the water quantity in barrels remaining in each
port tank.

Figure 12 shows the input data arrangement for a T2
class tanker.

## Symbols in the Program

COEFF - the partitioning coefficient at 80°F.

BBLINW - barrels of additive which will be absorbed by the
water on board.

0.997 - volume per cent of ethylene glycol monomethyl ether
in icing inhibitor.

BBLINF - barrels of additive required to satisfy the desired
additive concentration in the fuel after equilibrium.

PERINJ - volume per cent of icing inhibitor to be injected
into the fuel.

AFI - the initial additive quantity injected into a ship's
tank which will provide icing protection.

A,B,C - the coefficients of the quadratic equation used to
solve for the additive concentration in water at
equilibrium.

AW - the actual barrels of additive which will be absorbed by
the water in a particular ship's tank.

AIASTK(K) - the actual icing inhibitor concentration of the
fuel in each starboard tank after equilibrium.

AIACTK(M) - the actual icing inhibitor concentration of the
fuel in each center tank after equilibrium.

AIAPTK(N) - the actual icing inhibitor concentration of the
fuel in each port tank after equilibrium.

TOTICE - the total barrels of icing inhibitor in all the fuel
after equilibrium.

CONCEN - the average icing inhibitor concentration of the
total cargo at equilibrium.

AICCST - the additional cost per barrel of product if addi-
tional icing inhibitor must be injected.

AIACST - the total additional cost of the cargo due to the
requirement of increasing the icing inhibitor con-
tent.

HOURS - the point in time where drying cost equals cost to
increase icing inhibitor concentration.

## Output Examples

Output data for a T2 class tanker may be found in
Chapter VI. Figures 13a and 14a show output data for a vessel
having a tank arrangement unlike a T2. Figures 13b and 14b
show the respective economic analysis data sheets.

## The Program

The computer program follows the output examples dis-
cussed above.

```
0.14
2505.        3092.    9  3894.   8 0.0004  168.0   7.4           3744.
3592.                     3978.   3962.    3975.   3981.
9812.        9218.        9198.   9244.    5913.   9222.  9178.   9048.
2499.        3080.        3842.   3993.    3984.   3989.  3984.   3947.
3571.
0.31         0.31         0.31    0.43     0.38    0.40   0.52    0.5
0.81
0.86         0.45         1.0     0.57     1.1     0.67   1.40    0.85
0.31         0.31         0.31    0.43     0.38    0.40   0.52    0.5
0.81
```

Figure 12 – Input Data Arrangement for a T2 Tanker Simulation

A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.

3. TOTAL BARRELS OF PRODUCT LOADED = 257612.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 97.4
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.136 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.152 PERCENT MUST BE LOADED ABOARD THE VESSEL.

| STARBOARD TANK NUMBER | FUEL QUANTITY (BARRELS) | WATER QUANTITY (BARRELS) | ICING INHIBITOR CONTENT (PERCENT BY VOLUME) |
|---|---|---|---|
| 1 | 5002. | 2.0 | 0.135 |
| 2 | 5217. | 2.4 | 0.133 |
| 3 | 5632. | 1.9 | 0.137 |
| 4 | 5276. | 2.9 | 0.130 |
| 5 | 5124. | 2.1 | 0.128 |
| 6 | 5143. | 2.1 | 0.135 |
| 7 | 5633. | 3.4 | 0.128 |
| 8 | 5742. | 4.5 | 0.123 |
| 9 | 5214. | 2.4 | 0.133 |
| 10 | 5001. | 5.1 | 0.117 |

| CENTER TANK NUMBER | FUEL QUANTITY (BARRELS) | WATER QUANTITY (BARRELS) | ICING INHIBITOR CONTENT (PERCENT BY VOLUME) |
|---|---|---|---|
| 1 | 15000. | 2.0 | 0.142 |
| 2 | 15321. | 5.1 | 0.137 |
| 3 | 14900. | 4.3 | 0.139 |
| 4 | 15212. | 2.1 | 0.145 |
| 5 | 15421. | 4.5 | 0.139 |
| 6 | 15222. | 3.1 | 0.142 |
| 7 | 14934. | 2.0 | 0.145 |
| 8 | 15231. | 5.1 | 0.137 |
| 9 | 15000. | 3.2 | 0.142 |
| 10 | 15321. | 5.1 | 0.137 |

| PORT TANK NUMBER | FUEL QUANTITY (BARRELS) | WATER QUANTITY (BARRELS) | ICING INHIBITOR CONTENT (PERCENT BY VOLUME) |
|---|---|---|---|
| 1 | 5002. | 2.0 | 0.135 |
| 2 | 5217. | 2.4 | 0.133 |
| 3 | 5632. | 1.9 | 0.137 |
| 4 | 5276. | 2.9 | 0.130 |
| 5 | 5124. | 2.1 | 0.128 |
| 6 | 5143. | 2.1 | 0.135 |
| 7 | 5633. | 3.4 | 0.128 |
| 8 | 5742. | 4.5 | 0.123 |
| 9 | 5214. | 2.4 | 0.133 |
| 10 | 5001. | 5.1 | 0.117 |

Figure 13a - Simulation Output Data for a Tanker Other Than a T2

ECONOMIC ANALYSIS
----------------

COST TO DRY SHIP = $ 196.00 PER HOUR.

COST TO INCREASE ICING INHIBITOR CONCENTRATION OF THIS CARGO ABOVE 0.15 PERCENT = $ 4327.88

IF DRYING TIME IS   4 HOURS,AN ADDITIONAL COST OF $  3544. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.
IF DRYING TIME IS   8 HOURS,AN ADDITIONAL COST OF $  2760. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.
IF DRYING TIME IS  12 HOURS,AN ADDITIONAL COST OF $  1976. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.
IF DRYING TIME IS  16 HOURS,AN ADDITIONAL COST OF $  1192. WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL.
IF DRYING TIME IS  24 HOURS,$   376. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.
IF DRYING TIME IS  36 HOURS,$  2728. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.
IF DRYING TIME IS  48 HOURS,$  5080. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.
IF DRYING TIME IS  60 HOURS,$  7432. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.,
IF DRYING TIME IS  72 HOURS,$  9784. WILL BE SAVED BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYING TANKS.

IF DRYING TIME IS GREATER THAN 22.1 HOURS,IT WILL BE MORE ECONOMICAL TO ADD ADDITIONAL ICING INHIBITOR.

Figure 13b - Economic Analysis

A SIMULATION OF ICING INHIBITOR CONCENTRATIONS IN JP4 ABOARD A TANKER

1. DESIRED ANTI-ICING CONTENT OF TOTAL CARGO = 0.140 PERCENT.
2. MILITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.
3. TOTAL BARRELS OF PRODUCT LOADED = 257612.
4. TOTAL BARRELS OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIBLE = 97.4
5. IN ORDER TO COMBAT THE WATER ABOARD AND STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF 0.128 PERCENT, PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF 0.143 PERCENT MUST BE LOADED ABOARD THE VESSEL.
WATER ESTIMATE WAS 22.0 BARRELS.

| STARBOARD TANK NUMBER | FUEL QUANTITY (BARRELS) | WATER QUANTITY (BARRELS) | ICING INHIBITOR CONTENT (PERCENT BY VOLUME) |
| --- | --- | --- | --- |
| 1 | 5002. | 2.0 | 0.127 |
| 2 | 5217. | 2.4 | 0.125 |
| 3 | 5632. | 1.9 | 0.129 |
| 4 | 5276. | 2.9 | 0.122 |
| 5 | 5124. | 3.1 | 0.121 |
| 6 | 5143. | 2.1 | 0.127 |
| 7 | 5673. | 3.4 | 0.121 |
| 8 | 5742. | 4.5 | 0.116 |
| 9 | 5214. | 2.4 | 0.125 |
| 10 | 5001. | 5.1 | 0.110 |

| CENTER TANK NUMBER | FUEL QUANTITY (BARRELS) | WATER QUANTITY (BARRELS) | ICING INHIBITOR CONTENT (PERCENT BY VOLUME) |
| --- | --- | --- | --- |
| 1 | 15000. | 3.2 | 0.134 |
| 2 | 15321. | 5.1 | 0.129 |
| 3 | 14960. | 4.3 | 0.131 |
| 4 | 15218. | 2.6 | 0.137 |
| 5 | 15421. | 4.6 | 0.131 |
| 6 | 15204. | 3.1 | 0.134 |
| 7 | 14934. | 2.0 | 0.137 |
| 8 | 15231. | 5.1 | 0.129 |
| 9 | 15000. | 3.2 | 0.134 |
| 10 | 15321. | 5.1 | 0.129 |

| PORT TANK NUMBER | FUEL QUANTITY (BARRELS) | WATER QUANTITY (BARRELS) | ICING INHIBITOR CONTENT (PERCENT BY VOLUME) |
| --- | --- | --- | --- |
| 1 | 5002. | 2.0 | 0.127 |
| 2 | 5217. | 2.4 | 0.125 |
| 3 | 5632. | 1.9 | 0.129 |
| 4 | 5276. | 2.9 | 0.122 |
| 5 | 5124. | 3.1 | 0.121 |
| 6 | 5143. | 2.1 | 0.127 |
| 7 | 5673. | 3.4 | 0.121 |
| 8 | 5742. | 4.5 | 0.116 |
| 9 | 5214. | 2.4 | 0.125 |
| 10 | 5001. | 5.1 | 0.110 |

Figure 14a - Simulation Output Data for a Tanker Other Than a T2

ECONOMIC ANALYSIS
----------------

COST TO DRY SHIP = $ 196.00 PER HOUR.

THIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN ICING INHIBITOR CONCENTRATION OF 0.143. SINCE THIS CONCENTRATION IS NOT ABOVE
THE MAXIMUM MILITARY SPECIFICATION LIMIT OF 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INHIBITOR. THE FINAL
TOTAL CARGO INHIBITOR CONCENTRATION WILL BE 0.128 PERCENT. NO TANK DRYING IS REQUIRED AND THEREFORE ALL DRYING TIME COSTS ARE
SAVED.

IF DRYING TIME IS   4 HOURS,$    784. WILL BE SAVED.
IF DRYING TIME IS   8 HOURS,$   1568. WILL BE SAVED.
IF DRYING TIME IS  12 HOURS,$   2352. WILL BE SAVED.
IF DRYING TIME IS  16 HOURS,$   3136. WILL BE SAVED.
IF DRYING TIME IS  24 HOURS,$   4704. WILL BE SAVED.
IF DRYING TIME IS  36 HOURS,$   7056. WILL BE SAVED.
IF DRYING TIME IS  48 HOURS,$   9408. WILL BE SAVED.
IF DRYING TIME IS  60 HOURS,$  11760. WILL BE SAVED.
IF DRYING TIME IS  72 HOURS,$  14112. WILL BE SAVED.

Figure 14b - Economic Analysis

AN ICING INHIBITOR EQUILIBRIUM SIMULATION

```
C               AN ICING INHIBITOR EQUILIBRIUM SIMULATION
C                                                                          C
C.....................................................................C
C                                                                          C
C                                                                          C
C                                                                          C
C   A SIMULATION OF ICING INHIBITOR EQUILIBRIUM CONDITIONS ABOARD A TANKER  C
C                                                                          C
C                                                                          C
C.....................................................................C
      DIMENSION FUELS(15),FUELC(15),FUELP(15),WATERS(15),WATERC(15),WATE
     1RP(15),AIASTK(15),AIACTK(15),AIAPTK(15),TKCOST(100),ALOSS(100),GAI
     2N(100)
      COEFF=220.
CC READ IN DESIRED ICING INHIBITOR CONTENT OF TOTAL CARGO(IN PERCENT),NUMBER
CC    OF WING TANKS VESSEL HAS DIVIDED BY 2,NUMBER OF CENTER TANKS VESSEL HAS,
CC    ADDITIONAL COST PER GALLON OF PRODUCT IF ICING INHIBITOR TREATMENT EXCEEDS
CC    MAXIMUM SPECIFICATION LIMIT OF 0.15 PERCENT (COST IS READ IN $), COST
CC    PER HOUR TO OPERATE TANKER($),ESTIMATED BARRELS OF WATER REMAINING ABOARD
CC    TANKER(OPTIONAL)
    1 READ(5,201)DESAIA,NUMWTK,NUMCTK,PRICE,DRYCST,H2OEST                    2
  201 FORMAT(F10.3,2I10,F10.5,2F10.2)                                        7
      IF(DESAIA.EQ.0.0)GO TO 999                                            7
CC    READ IN FUEL QUANTITIES FROM BOW TO STERN FOR EACH CARGO TANK IN
CC    FOLLOWING ORDER - ALL STARBOARD TANKS, ALL CENTER, ALL PORT TANKS
      READ(5,202)(FUELS(I),I=1,NUMWTK)                                      10
      READ(5,202)(FUELC(I),I=1,NUMCTK)                                      15
      READ(5,202)(FUELP(I),I=1,NUMWTK)                                      20
  202 FORMAT(8F10.0)                                                        25
CC    READ IN ACTUAL WATER QUANTITIES IN SAME ORDER AS FUEL
      READ(5,203)(WATERS(I),I=1,NUMWTK)                                     25
      READ(5,203)(WATERC(I),I=1,NUMCTK)                                     30
      READ(5,203)(WATERP(I),I=1,NUMWTK)                                     35
  203 FORMAT(8F10.1)                                                        40
CC    DESIRED AVERAGE ICING INHIBITOR SETS ESTIMATED PERCENTAGE OF ADDITIVE
CC    TO BE ABSORBED BY WATER
      IF(DESAIA.EQ.0.15)ABSPER=0.335                                        40
      IF(DESAIA.EQ.0.14)ABSPER=0.310                                        43
      IF(DESAIA.EQ.0.13)ABSPER=0.295                                        46
      IF(DESAIA.EQ.0.12)ABSPER=0.265                                        49
      IF(DESAIA.EQ.0.11)ABSPER=0.245                                        52
      IF(DESAIA.EQ.0.10)ABSPER=0.220                                        55
CC    WATER AND FUEL QUANTITIES ARE SUMMED UP
      WATER1=0.0                                                            58
      WATER2=0.0                                                            59
      WATER3=0.0                                                            60
      SUM1=0.0                                                              61
      SUM2=0.0                                                              62
      SUM3=0.0                                                              63
      DO 2N=1,NUMWTK                                                        64
      SUM2=FUELS(N)+SUM2                                                    65
```

```
        WATER2=WATERS(N)+WATER2                                          66
        SUM1=FUELP(N)+SUM1                                               67
        WATER1=WATERP(N)+WATER1                                          68
      2 CONTINUE                                                         69
        DO 3J=1,NUMCTK                                                   70
        SUM3=FUELC(J)+SUM3                                               72
        WATER3=WATERC(J)+WATER3                                          73
      3 CONTINUE                                                         74
        FUEL=SUM1+SUM2+SUM3                                              76
        TOTH2O=WATER1+WATER2+WATER3                                      77
CC      IF NO WATER ESTIMATE IS PROVIDED, THE ADDITIONAL BARRELS OF ADDITIVE
CC      REQUIRED ARE CALCULATED USING THE ACTUAL WATER QUANTITY
        IF(H2OEST.EQ.0.0)GO TO 4                                         78
CC      IF A WATER ESTIMATE IS PROVIDED, THE ADDITIONAL BARRELS OF ADDITIVE
CC      REQUIRED ARE CALCULATED USING THE ESTIMATED WATER QUANTITY
        BBLINW=ABSPER*H2OEST/0.997                                       81
        GO TO 5                                                          82
      4 BBLINW=ABSPER*TOTH2O/0.997                                       83
CC      BARRELS OF ADDITIVE TO SATISFY DESIRED INHIBITOR CONTENT OF FUEL ARE
CC      DETERMINED
      5 BBLINF=(DESAIA/100.*(FUEL-BBLINW))/0.997                         84
CC      TOTAL BARRELS OF ICING INHIBITOR TO BE ADDED TO CARGO ARE DETERMINED
        TOTAIA=BBLINF+BBLINW                                             85
        AIAINJ=TOTAIA/FUEL                                               86
        PERINJ=AIAINJ*100.                                              87
CC      ICING INHIBITOR CONCENTRATION OF STARBOARD TANKS ARE DETERMINED AFTER
CC      EQUILIBRIUM HAS BEEN ESTABLISHED
        DO 6 K=1,NUMWTK                                                  88
        IF(FUELS(K).EQ.0.0)GO TO 7                                       89
        AFI=FUELS(K)*AIAINJ*0.997                                        92
        A=COEFF/FUELS(K)                                                 93
        B=(A*WATERS(K))-(A*AFI)+1.0                                      94
        C=-A*WATERS(K)*AFI                                               95
        AW=(-B+SQRT((B**2.)-(4.*A*C)))/(2.*A)                           96
        AIASTK(K)=((AFI-AW)*100.)/FUELS(K)                              97
        GO TO 6                                                          98
      7 AIASTK(K)=0.0                                                    99
      6 CONTINUE                                                        100
CC      ICING INHIBITOR CONCENTRATION OF CENTER TANKS ARE DETERMINED AFTER
CC      EQUILIBRIUM HAS BEEN ESTABLISHED
        DO 8 M=1,NUMCTK                                                 102
        IF(FUELC(M).EQ.0.0)GO TO 9                                      103
        AFI=FUELC(M)*AIAINJ*0.997                                       106
        A=COEFF/FUELC(M)                                                107
        B=(A*WATERC(M))-(A*AFI)+1.0                                     108
        C=-A*WATERC(M)*AFI                                              109
        AW=(-B+SQRT((B**2.)-(4.*A*C)))/(2.*A)                          110
        AIACTK(M)=((AFI-AW)*100.)/FUELC(M)                             111
        GO TO 8                                                         112
      9 AIACTK(M)=0.0                                                   113
```

```
      8 CONTINUE                                                          114
CC      ICING INHIBITOR CONCENTRATION OF PORT TANKS ARE DETERMINED AFTER
CC      EQUILIBRIUM HAS BEEN ESTABLISHED
        DO 10N=1,NUMWTK                                                   116
        IF(FUELP(N).EQ.0.0)GO TO 11                                      117
        AFI=FUELP(N)*AIAINJ*0.997                                        120
        A=COEFF/FUELP(N)                                                 121
        B=(A*WATERP(N))-(A*AFI)+1.0                                      122
        C=-A*WATERP(N)*AFI                                               123
        AW=(-B+SQRT((B**2.)-(4.*A*C)))/(2.*A)                            124
        AIAPTK(N)=((AFI-AW)*100.)/FUELP(N)                               125
        GO TO 10                                                         126
     11 AIAPTK(N)=0.0                                                    127
     10 CONTINUE                                                         128
CC      THE BARRELS OF ICING INHIBITOR IN THE FUEL IN EACH TANK IS DETERMINED
CC      AND THEY ARE SUMMED.
        BLICES=0.0                                                       130
        BLICEP=0.0                                                       131
        BLICEC=0.0                                                       132
        DO 12 I=1,NUMWTK                                                 133
        BLICES=((AIASTK(I)*FUELS(I))/100.)+BLICES                        134
        BLICEP=((AIAPTK(I)*FUELP(I))/100.)+BLICEP                        135
     12 CONTINUE                                                         136
        DO 13 J=1,NUMCTK                                                 138
        BLICEC=((AIACTK(J)*FUELC(J))/100.)+BLICEC                        139
     13 CONTINUE                                                         140
        TOTICE=BLICEC+BLICEP+BLICES                                      142
CC      THE ACTUAL ICING INHIBITOR CONCENTRATION OF THE TOTAL CARGO IS DETERMINED
        CONCEN=(TOTICE/FUEL)*100.                                        143
CC      IF THE VESSEL HAS MORE THAN 8 CENTER TANKS IT IS NOT A T-2 AND TABULAR
CC      RESULTS ARE WRITTEN OUT, IF THE SHIP HAS 8 CENTER TANKS,IT IS ASSUMED
CC      THE TANK LAYOUT IS THE SAME AS THAT OF A T-2, A DIAGRAM IS PRODUCED AND
CC      THE RESULTS ARE NOTED ON THE DIAGRAM.
        IF(NUMCTK.EQ.8)GO TO 14                                          144
        GO TO 15                                                         147
     14 WRITE(6,100)                                                     148
    100 FORMAT(1H1)                                                      150
        WRITE(6,101)DESAIA,FUEL,TOTH2O,CONCEN,PERINJ                     150
    101 FORMAT(    29X,73HA SIMULATION OF ICING INHIBITOR CONCENTRATIONS I    153
       1N JP4 ABOARD A T-2 TANKER,/,30X,73H------------------------------
       2-------------------------------,//,36X,46H1. DESIRED AN
       3TI-ICING CONTENT OF TOTAL CARGO =,F6.3,9H PERCENT.,/,33X,65H2. MIL
       4ITARY SPECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.,//,44X,
       536H3. TOTAL BARRELS OF PRODUCT LOADED =,F8.0,/,18X,
       5                                           9H4. TOTAL BARRELS
       6 OF WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS PO
       7SSIBLE =,F6.1,/,12X,102H5. IN ORDER TO COMBAT THE WATER ABOARD AND
       8 STILL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF,F6.3,
       9/,13X,57H PERCENT,PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF
       1,F6.3,42H PERCENT MUST BE LOADED ABOARD THE VESSEL.,//,31X70HTHE D
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      2IAGRAM BELOW INDICATES THE BARRELS OF PRODUCT IN EACH SHIPS TANK,,
      3/,31X,71H(BARRELS OF PRODUCT EQUALS BARRELS OF JP4 + BARRELS OF IC
      4ING INHIBITOR),//,25X,1H2,12X,1H3,12X,1H4,12X,1H5,12X,1H6,12X,1H7,
      512X,1H8,12X,1H9)
        WRITE(6,102)FUELS(2),FUELS(3),FUELS(4),FUELS(5),FUELS(6),FUELS(7),    153
      1FUELS(8),FUELS(9)
  102 FORMAT(19X,105H-----------------------------------------------------    156
      1-------------------------------------------------,/,17X1H*,1X
      2,1FI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1
      3HI,/,15X,1H*,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2
      4X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1
      5,3X,1HI,4HSTBD,/,13X,1H*,5X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12
      6X,1HI,12X,1HI,12X,1HI,12X,1HI,/,
      38X,2H 1,1X,1H*,7X,1HI,12X,1HI,12X,1HI,12X
      7,1FI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/, 9X,1H*,9X,1HI,12H-
      8-----------,1HI,12H------------,1HI,12H-----------,1HI,12H-------
      9-----,1HI,12H-----------,1HI,12H-----------,1HI,12H-----------,
      11HI,12H-----------,1HI)
        WRITE(6,103)FUELS(1),FUELC(1),FUELC(2),FUELC(3),FUELC(4),FUELC(5),    156
      1FUELC(6),FUELC(7),FUELC(8),FUELP(1),FUELP(2),FUELP(3),FUELP(4),FUE
      2LP(5),FUELP(6),FUELP(7),FUELP(8),FUELP(9)
  103 FORMAT(7X,1H*,2X,F7,1,2X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1    159
      1HI,12X,1HI,12X,1HI,12X,1HI,/,5X,1H*,13X,1HI,12X,1HI,12X,1HI,12X,1H
      2I,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,3X,1H*,15X,1HI,12X,1HI
      3,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,1X,1H*,
      417H-----------------,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,
      51HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X
      6,F7,1,3X,1HI,6HCENTER,/,3X,1H*,15X,1HI,12X,1HI,12X,1HI,12X,1HI,12X
      7,1FI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,5X,1H*,13X,1HI,12X,1HI,12X,
      81HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,7X,1H*,2X,F7
      9,1,2X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,
      112X,1HI,/, 9X,1H*,9X,1HI,12H-----------,1HI,12H-----------,1HI,1
      12H-----------,1HI,12H-----------,1HI,12H-----------,1HI,12H----
      2-----------,1HI,12H-----------,1HI,/,11X,1H*,7X,
      31HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1H
      4I,/,13X,1H*,5X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI
      5,12X,1HI,12X,1HI,/,15X,1H*,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X
      6,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,3X,1HI,2X,F7,1,
      73X,1HI,2X,F7,1,3X,1HI,4HPORT,/,17X,1H*,1X,1HI,12X,1HI,12X,1HI,12X,
      81HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI)
        WRITE(6,104)                                                          159
  104 FORMAT(19X,105H-----------------------------------------------------    161
      1-------------------------------------------------,///,23X,75H
      2THE DIAGRAM BELOW INDICATES THE BARRELS OF WATER IN EACH SHIPS TAN
      3K AND THE,/,24X,84HRESULTING ICING INHIBITOR CONCENTRATION IN PERC
      4ENT BY VOLUME AFTER WATER EXTRACTION,)
        IF(H2OEST.EQ.0.0)GO TO 16                                             161
        WRITE(6,105)H2OEST                                                    164
  105 FORMAT(30X,18HWATER ESTIMATE WAS,F6,1,9H BARRELS,)                      167
   16 WRITE(6,106)                                                            167
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AN ICING INHIBITOR EQUILIBRIUM SIMULATION000000

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106 FORMAT(/ ,25X,1H2,12X,1H3,12X,1H4,12X,1H5,12X,1H6,12X,1H7,12X,1H8,    169
   112X,1H9)
      WRITE(6,107)WATERS(2),WATERS(3),WATERS(4),WATERS(5),WATERS(6),WATE    169
   1RS(7),WATERS(8),WATERS(9),AIASTK(2),AIASTK(3),AIASTK(4),AIASTK(5),
   2AIASTK(6),AIASTK(7),AIASTK(8),AIASTK(9),WATERS(1),AIASTK(1),WATERC
   3(1),WATERC(2),WATERC(3),WATERC(4),WATERC(5),WATERC(6),WATERC(7),WA
   4TERC(8)
  107 FORMAT(19X,105H----------------------------------------------------    172
   1------------------------------------------,/,17X1H*,1X
   2,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1
   3HI,/,15X,1H*,3X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3
   4X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1
   5,4X,1HI,4HSTRD,//,13X,1H*,5X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F
   66.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X
   7,1HI,3X,F6.3,3X,1HI,/,8X,2H 1,1X,1H*,7X,1HI,12X,1HI,12X,1HI,12X,1H
   8I,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,9X,1H*,9X,1HI,12H-----
   9---------,1HI,12H-----------,1HI,12H-----------,1HI,12H-----------
   1-,1HI,12H-----------,1HI,12H-----------,1HI,12H-----------,1HI,
   212H-----------,1HI,/,7X,1H*,2X,F5.1,4X,1HI,12X,1HI,12X,1HI,12X,1H
   3I,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,5X,1H*,4X,F6.3,3X,1HI,
   412X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,
   53X,1H*,15X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X
   6,1HI,12X,1HI,/,1X,1H*,17H-----------------,1HI,3X,F5.1,4X,1HI,3X,F
   75.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X
   8,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,6HCENTER)
      WRITE(6,108)AIACTK(1),AIACTK(2),AIACTK(3),AIACTK(4),AIACTK(5),AIAC    172
   1TK(6),AIACTK(7),AIACTK(8),WATERP(1),AIAPTK(1),WATERP(2),WATERP(3),
   2WATERP(4),WATERP(5),WATERP(6),WATERP(7),WATERP(8),WATERP(9),AIAPTK
   3(2),AIAPTK(3),AIAPTK(4),AIAPTK(5),AIAPTK(6),AIAPTK(7),AIAPTK(8),AI
   4APTK(9)
  108 FORMAT(3X,1H*,15X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI    175
   1,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6
   2.3,3X,1HI,/,5X,1H*,4X,F5.1,4X,1HI,12X,1HI,12X,1HI,12X,1HI,
   312X,1HI,12X,1HI,12X,1HI,12X,1HI,/,7X,1H*,2X,F6.3,3X,1HI,12X,1HI,12
   4X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,9X,1H*,9X,
   51HI,12H-----------,1HI,12H-----------,1HI,12H-----------,1HI,12
   6H-----------,1HI,12H-----------,1HI,12H-----------,1HI,12H-----
   7-----------,1HI,12H-----------,1HI,/,11X,1H*,7X,1HI,12X,1HI,12X,1HI,1
   82X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,/,13X,1H*,5X,1HI,3X
   9,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,
   14X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,3X,F5.1,4X,1HI,/,15X,1H*,3X,1
   2HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,
   7 F6.3,
   3     3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,3X,F6.3,3X,1HI,4HPORT,/,1
   47X,1H*,1X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,1HI,12X,
   51HI,12X,1HI,/,19X,105H-----------------------------------------------
   6---------------------------------------)
      GO TO 17                                                             175
   15 WRITE(6,109)                                                         176
  109 FORMAT(1H1)                                                          178
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AN ICING INHIBITOR EQUILIBRIUM SIMULATION000000

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      WRITE(6,110)DESAIA,FUEL,TOTH2O,CONCEN,PERINJ                        178
  110 FORMAT( / ,29X,69HA SIMULATION OF ICING INHIBITOR CONCENTRATIONS I   181
     1N JP4 ABOARD A TANKER,/,30X,69H-------------------------------------
     2---------------------------------,//,36X,46H1, DESIRED ANTI-ICING
     3 CONTENT OF TOTAL CARGO =,F6.3,9H PERCENT,/,33X,65H2, MILITARY SP
     4ECIFICATION LIMITS ARE 0.10-0.15 PERCENT BY VOLUME.,/,44X,36H3, TO
     5TAL BARRELS OF PRODUCT LOADED =,F8.0,/,18X,90H4, TOTAL BARRELS OF
     6WATER REMAINING ABOARD AFTER STRIPPING THE VESSEL AS DRY AS POSSIB
     7LE =,F6.1,/,12X,102H5, IN ORDER TO COMBAT THE WATER ABOARD AND STI
     8LL OBTAIN A FINAL TOTAL ICING INHIBITOR CONCENTRATION OF,F6.3,/,13
     9X,57H PERCENT,PRODUCT WITH AN ICING INHIBITOR CONCENTRATION OF,F6.
     13,42H PERCENT MUST BE LOADED ABOARD THE VESSEL.)
      IF(H2OEST.EQ.0.0)GO TO 28                                           181
      WRITE(6,127)H2OEST                                                  184
  127 FORMAT(50X,18HWATER ESTIMATE WAS,F6.1,9H BARRELS.)                  187
   28 WRITE(6,128)                                                        187
  128 FORMAT(/,32X,9HSTARBOARD,  4X,13HFUEL QUANTITY,3X,14HWATER QUANTITY  189
     1,3X,23HICING INHIBITOR CONTENT,/,31X,11HTANK NUMBER,5X,9H(BARRELS)
     2,7X,9H(BARRELS),8X,19H(PERCENT BY VOLUME),/,31X,11H-----------,5X,
     39H---------,7X,9H---------,8X,19H-------------------,/)
      DO 18 I=1,NUMWTK                                                     189
   18 WRITE(6,111)I,FUELS(I),WATERS(I),AIASTK(I)                          190
  111 FORMAT(34X,I3,10X,F8.0,10X,F5.1,16X,F6.3)                           194
      WRITE(6,112)                                                        194
  112 FORMAT(///     ,33X,6HCENTER,5X,13HFUEL QUANTITY,3X,14HWATER QUAN    196
     1TITY,3X,23HICING INHIBITOR CONTENT,/,31X,11HTANK NUMBER,5X,9H(BARR
     2ELS),7X,9H(BARRELS),8X,19H(PERCENT BY VOLUME),/,31X,11H-----------
     3,5X,9H---------,7X,9H---------,8X,19H-------------------,/)
      DO 19 K=1,NUMCTK                                                     196
   19 WRITE(6,113)K,FUELC(K),WATERC(K),AIACTK(K)                          197
  113 FORMAT(34X,I3,10X,F8.0,10X,F5.1,16X,F6.3)                           201
      WRITE(6,114)                                                        201
  114 FORMAT(///     ,34X,4HPORT,7X,13HFUEL QUANTITY,3X,14HWATER QUANTIT   203
     1Y,3X,23HICING INHIBITOR CONTENT,/,31X,11HTANK NUMBER,5X,9H(BARRELS
     2),7X9H(BARRELS),8X,19H(PERCENT BY VOLUME),/,31X,11H-----------,5X,
     39H---------,7X,9H---------,8X,19H-------------------,/)
      DO 20 J=1,NUMWTK                                                     203
   20 WRITE(6,115)J,FUELP(J),WATERP(J),AIAPTK(J)                          204
  115 FORMAT(34X,I3,10X,F8.0,10X,F5.1,16X,F6.3)                           208
   17 WRITE(6,116)                                                        208
  116 FORMAT(1H1,            ///////////////////,57X,17HECONOMIC ANALYSIS,/,  210
     157X,17H-----------------,//)
   CC IF THE FUEL PUMPED TO THE SHIP HAS AN ICING INHIBITOR CONCENTRATION
   CC GREATER THAN 0.150 PERCENT, AN ADDITIONAL COST IS CHARGED FOR THE EXTRA
   CC INHIBITOR.
      IF(PERINJ.LE.0.15)GO TO 25                                          210
      AICCST=42.*PRICE                                                    213
   CC THE TOTAL COST OF THE ADDITIONAL ICING INHIBITOR IS DETERMINED.
      AIACST=AICCST*FUPL                                                  214
   CC THE POINT AT WHICH DRYING COST EQUALS ADDITIONAL ICING INHIBITOR COST
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CC      IS DETERMINED.
        HOURS=AIACST/DRYCST                                                      215
        WRITE(6,117)DRYCST,AIACST                                                216
  117 FORMAT(48X,20HCOST TO DRY SHIP = $,F7.2,10H PER HOUR.,/,20X,83HCOS         219
     1T TO INCREASE ICING INHIBITOR CONCENTRATION OF THIS CARGO ABOVE 0.,
     2 215 PERCENT = $,F8.2,//)
CC      VARIOUS DRYING TIMES ARE ASSUMED AND THE COST (OR SAVINGS) RESULTING
CC      FROM INJECTING ADDITIONAL ICING INHIBITOR IS DETERMINED.
        DO 21 I=4,16,4                                                           219
        HOURR=I                                                                  220
        TKCOST(I)=HOURR*DRYCST                                                   221
        IF(TKCOST(I).GT.AIACST)GO TO 22                                          222
        ALOSS(I)=AIACST-TKCOST(I)                                                225
        WRITE(6,118)I,ALOSS(I)                                                   226
  118 FORMAT(2X,17HIF DRYING TIME IS,I3,30H HOURS,AN ADDITIONAL COST OF          229
     1$,F7.0,72H WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONT
     2ENT OF THE FUEL.,/)
        GO TO 21                                                                 229
   22 GAIN(I)=TKCOST(I)-AIACST                                                   230
        WRITE(6,119)I,GAIN(I)                                                    231
  119 FORMAT(6X,17HIF DRYING TIME IS,I3,8H HOURS,$,F7.0,87H WILL BE SAVE         234
     1D BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYIN
     2G TANKS.)
   21 CONTINUE                                                                   234
        DO 23 N=24,72,12                                                         236
        HOURR=N                                                                  237
        TKCOST(N)=HOURR*DRYCST                                                   238
        IF(TKCOST(N).GT.AIACST)GO TO 24                                          239
        ALOSS(N)=AIACST-TKCOST(N)                                               242
        WRITE(6,120)N,ALOSS(N)                                                   243
  120 FORMAT(2X,17HIF DRYING TIME IS,I3,30H HOURS,AN ADDITIONAL COST OF          246
     1$,F7.0,72H WILL BE INCURRED BY INCREASING THE ICING INHIBITOR CONT
     2ENT OF THE FUEL.,/)
        GO TO 23                                                                 246
   24 GAIN(N)=TKCOST(N)-AIACST                                                   247
        WRITE(6,121)N,GAIN(N)                                                    248
  121 FORMAT(6X,17HIF DRYING TIME IS,I3,8H HOURS,$,F7.0,87H WILL BE SAVE         251
     1D BY INCREASING THE ICING INHIBITOR CONTENT OF THE FUEL VICE DRYIN
     2G TANKS.)
   23 CONTINUE                                                                   251
        WRITE(6,122)HOURS                                                        253
  122 FORMAT(///,14X,30HIF DRYING TIME IS GREATER THAN,F6.1,68H HOURS,IT         256
     1 WILL BE MORE ECONOMICAL TO ADD ADDITIONAL ICING INHIBITOR.)
        GO TO 1                                                                  256
CC      IF THE FUEL PUMPED TO THE VESSEL HAS AN ICING INHIBITOR CONCENTRATION NOT
CC      EXCEEDING 0.150 PERCENT, THERE ARE NO ADDITIONAL ANTI-ICING COSTS
   25 WRITE(6,123)DRYCST                                                         257
  123 FORMAT(48X,20HCOST TO DRY SHIP = $,F7.2,10H PER HOUR.,//)                  260
        WRITE(6,124)PERINJ,CONCEN                                                260
  124 FORMAT(  3X,80HTHIS SHIP MUST BE LOADED WITH PRODUCT HAVING AN I           263
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AN ICING INHIBITOR EQUILIBRIUM SIMULATION000000

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     1ICING INHIBITOR CONCENTRATION OF,F6.3,39H. SINCE THIS CONCENTRATION
     2 IS NOT ABOVE,/,3X,126HTHE MAXIMUM MILITARY SPECIFICATION LIMIT OF
     3 0.15 PERCENT, THERE IS NO ADDITIONAL COST FOR INCREASED ICING INH
     4.IBITOR, THE FINAL,/,3X,43HTOTAL CARGO INHIBITOR CONCENTRATION WILL
     5 BE,F6.3,76H PERCENT. NO TANK DRYING IS REQUIRED AND THEREFORE ALL
     7 DRYING TIME COSTS ARE,/,3X,6HSAVED,,//)
CC      COSTS WHICH WILL BE SAVED BY NOT DRYING ARE DETERMINED BY ASSUMING VARIOUS
CC      DRYING TIMES,
        DO 26 K=4,16,4                                                    263
        HOURR=K                                                          264
        TKCOST(K)=HOURR*DRYCST                                           265
        WRITE(6,125)K,TKCOST(K)                                         266
    125 FORMAT(41X,17HIF DRYING TIME IS,I3,8H HOURS,$,F7.0,15H WILL BE SAV  269
       1ED.)
     26 CONTINUE                                                          269
        DO 27 M=24,72,12                                                  271
        HOURR=M                                                           272
        TKCOST(M)=HOURR*DRYCST                                            273
        WRITE(6,126)M,TKCOST(M)                                          274
    126 FORMAT(41X,17HIF DRYING TIME IS,I3,8H HOURS,$,F7.0,15H WILL BE SAV  277
       1ED.)
     27 CONTINUE                                                          277
        GO TO 1                                                           279
    999 STOP                                                              280
        END                                                              281
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